UNCANNILY HUMAN

Experimental Investigation of the Uncanny Valley Phenomenon

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Astrid Marieke Rosenthal-von der Pütten

aus

Neuss

1. Gutachter: Prof. Dr. Nicole C. Krämer

2. Gutachter: Prof. Dr. Matthias Brand

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Overviews and theoretical contributions

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Study 2

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Study 4

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I. Abstract

Since its introduction into scientific discourse in 1970 (Mori, 1970; Mori et al., 2012) the uncanny valley has been a highly discussed and referenced theory in the field of robotics. Although the theory was postulated more than 40 years ago, it has barely been tested empirically. However, in the last seven years robot scientists addressed themselves to the task of investigating the uncanny valley more systematically. But there are still open questions, some of which have been addressed within this research in the course of four consecutive studies. This project focussed on the systematic investigation of how static and dynamic characteristics of robots such as appearance and movement determine evaluations of and behavior towards robots. The work applied a multi-methodological approach and the various observed effects were examined with regard to their importance for the assumed uncanny valley. In addition, previously proposed explanations for the uncanny valley effect were tested.

The first study utilized qualitative interviews in which participants were presented with pictures and videos of humanoid and android robots to explore participants' evaluations of very human-like robots, their attitudes about these robots, and their emotional reactions towards these robots. Results showed that emotional experiences, if existent, were very individual. The robots' appearance was of great importance for the participants, because certain characteristics were equalized with certain abilities, merely human appearance without a connected functionality was not appreciated, and human rules of attractiveness were applied to the android robots. The analysis also demonstrated the importance of the robots' movements and the social context they were placed in. First evidence was found supporting the assumption that participants experienced uncertainty how to categorize android robots (as human or machine) and that they felt uncomfortable at the thought to be replaced by robots.

The influence of movement, as one of the important factors in the uncanny valley hypothesis, was examined in the second study. In a quasi-experimental observational field study people were confronted with the android robot Geminoid HI-1 either moving or not moving. These interactions between humans and the android robot were analyzed with regard to the participants' nonverbal behavior (e.g. attention paid to the robot, proximity). Results show that participants' behavior towards the android robot was influenced by the behavior the robot displayed. For instance, when the robot established eye-contact participants engaged in longer interactions, also established more eye-contact and tried to test the robots' capabilities. The robot's behavior served as cue for the participants to categorize the robot as such.

The aspect of robot appearances was examined systematically in the third study in order to identify certain robot attractiveness indices or design characteristics which determine how people perceive robots. A web-based survey was conducted with standardized pictures of 40 different mechanoid, humanoid and android robots. A cluster analysis revealed six clusters of robots which were rated significantly different on six dimensions. Possible relationships of design characteristics and the evaluation of robots have been outlined. Moreover, it has been tested whether the data of this study can best be explained by a cubic funtion as would be suggested by the graph proposed by Mori. Results revealed that the data can be best explained by linear or quadratic relationships.

The last study systematically tested perception-oriented and evolutionary-biological approaches for the uncanny valley. In this multi-methodological study, self-report and behavioral data were combined with functional magnetic resonance imaging techniques in order to examine whether the observed effects in self-report and behavior occur due to a) additional processing during face perception of human and robotic stimuli, b) automatically elicited processes of social cognition, or c) oversensitivity of the behavioral immune system. The study found strong support for perception-oriented explanations for the uncanny valley effect. First, effects seem to be driven by face perception processes. Further, there were indicators for the assumption that categorical perception takes place. In the contrary, evolutionary-biological driven explanations assuming that uncanny valley related reactions are due to oversensitivity of the behavioral immune system were not supported by this work.

Altogether, this dissertation explored the importance of characteristics of robots which are relevant for the uncanny valley hypothesis. Uncanny valley related responses were examined using a variety of measures, for instance, self-reporting, behavior, and brain activation, allowing conclusions with regard to the influence of the choice of measurements on the detection of uncanny valley related responses. Most importantly, explanations for the uncanny valley were tested systematically and support was found for cognitive-oriented and perception-oriented explanations.

II. INTRODUCTION

Since Karel Čapek's science fiction play *R.U.R. - Rossum's Universal Robots* in 1920 and Isaac Asimov's books like "I, robot" (1950), robots - especially humanoid and android robots - are part of our popular culture. The advantages and risks they bring, as well as moral and ethical questions concerning artificial life of very human-like or android robots are core themes in numerous books and movies. But it is only with the recent advancements in robotics that robots are also becoming more salient in public discourse with regard to the actual applicability of robots to support or accompany us in our daily lives.

Nowadays, the development of robots is considered to have the potential to solve major societal problems (e.g. compensate for decreasing numbers of healthcare employees by providing support in low-priority tasks (Onishi et al., 2007); support in rehabilitation of post-stroke participants (Matarić, 2006; Matarić, Eriksson, Feil-Seifer, & Winstein, 2007) indicated by the increasing number of funded research projects. A controversial topic has been and still is how robots should be designed. While some scholars follow a minimal design approach when designing robots (e.g. Blow, Dautenhahn, Appleby, Nehaniv, & Lee, 2006; Matsumoto, Fujii, & Okada, 2006) others favor robots resembling humans in detail (Ishiguro, 2006). Ishiguro (2006) stated that "humanoids and androids have a possibility to become ideal human interfaces accepted by all generations" (p.2), because they provide all communicative channels already known to humans. This assumption stands at least partly in contrast to the uncanny valley hypothesis (Mori, 1970). The uncanny valley hypothesis assumes that people will react increasingly positively towards increasingly human-like robots until a certain peak is reached, after which the effect reverses, resulting in negative reactions. Although android robots look very human-like, their behavior can often not match up to their appearance thereby breaking the illusion of human-likeness. This is considered to elicit uncanny valley responses. The uncanny valley theory has been put into question and has been critically discussed by several researchers (e.g. Brenton, Gillies, Ballin, & Chatting, 2005; Hanson, 2006, Pollick, 2010) who pointed out its conceptual shortcomings and the lack of empirical evidence on the topic. Moreover, there have been attempts to revise or refine Mori's thought experiment in order to transform it into a more fine-grained theory (e.g. Bartneck et al., 2007; Gee, Browne, & Kawamura, 2005; Ishiguro, 2006). Still a lot of questions remain unanswered, for instance what exactly are the negative or even repulsive reactions and when do they occur, do they stem from emotional or cognitive processes and how may these reactions be explained. Moreover, it is unclear whether the effect is just a spontaneous short-term reaction which can be overcome by habituation (cf. Brenton et al., 2005; Pollick, 2010; Ramey, 2006). While not all of the open questions can be addressed here, several aspects will be focused on, such as the influence of robotic movement on participants' perception of robots or their actual behavior (Study 1 & 2), the importance of appearance with regard to the perception and evaluation of robots (Study 1 & 3), and the testing of possible explanations for the uncanny valley related reactions (Study 4).

The following sections will review the history of both automata and the concept of "the uncanny" (section II.1) as well as give an introduction to the uncanny valley hypothesis, its history, and its reception (section II.2). Subsequently, section II.3 will introduce the reader to the different explanations for the uncanny valley effect which have been proposed in the last years and summarize critique and revised models of the uncanny valley. Empirical work on the uncanny valley hypothesis, the proposed explanations and related topics will be presented in section II.4. The introduction concludes with a summary and the derived research objectives and hypotheses which drove this work (section II.5).

1. Working definitions and a brief history of automata, the uncanny and robots

> "You can't define a robot. It's the same as trying to define Mt. Fuji. If a steep hill suddenly protrudes from the flatland, you can draw a line to show where the mountain starts, but Mt. Fuji becomes higher so gradually that you can't draw a line. Robots are like Mt. Fuji. It's hard to separate what is a robot from what is not. Asimo is so near the peak, anyone can easily call it a robot. But what about a dishwasher? It can automatically wash dishes, so you might call it a robot. The line is blurry."
>
> ("An Uncanny Mind")

The idea of creating artificial life can be traced back to antiquity. For example, in Homer's *Odyssey* the island Crete is guarded by the living titan bronze statue Talos. Tales of living statues and golems appeared over and over again and also attempts to build automata have not been restricted to the last decades, but reach far back in history. Engineering drawings of Leonardo da Vinci have been found showing construction plans for a robot in the shape of a knight (cf. Figure 1). During the Age of Enlightenment mechanical clocks and automata were very popular. The most famous example is certainly Wolfgang von Kempelen's chess playing automata also known as *The Turk* (cf. Figure 2) which was a fraud, but nevertheless exemplary. Another famous example is the mechanical duck by Jacques de Vaucanson from 1738 which was designed to imitate vitally important behavior like eating and digesting (cf. Figure 4). Between 1768 and 1774, Pierre and Henri-Louis Jaquet-Droz built androids performing different tasks: playing transverse flute, writing a letter, playing the organ (cf. Figure 3). A similar positive attitude towards automata can be found also in eastern cultures: Japan, for instance, has a long tradition of Puppet Theater (bunraku puppets) and during the 18th century also in Japan android automata were built (karakuri automata) similar to those of Pierre and Henri Louis Jaquet-Droz.

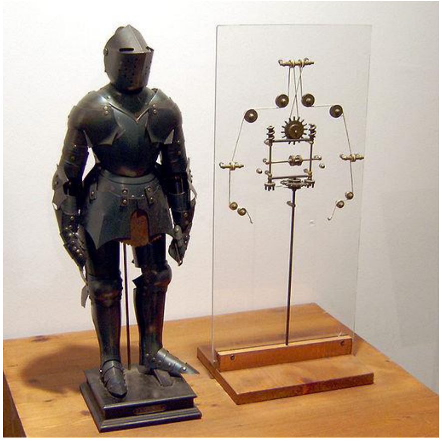


Figure 1: Model of a robot based on drawings by Leonardo da Vinci.

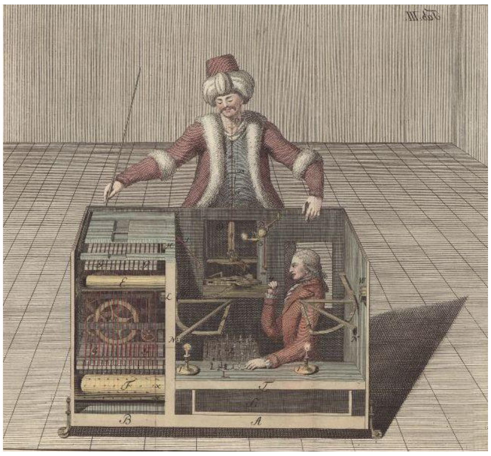


Figure 2: Chess playing automaton *The Turk* (Freiherr zu Racknitz, 1789)

Figure 3: Jaquet-Droz automata, musée d'Art et d'Histoire de Neuchâtel.

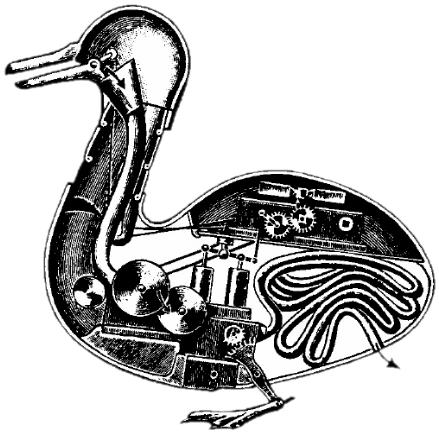


Figure 4: Mechanical Duck, built by Jaques de Vaucanson (1738, France)

In the Western culture, the overall positive attitudes towards artificial life changed completely during romanticism. Novels like Mary W. Shelley's *Frankenstein* deal with the issue that an artificial creature may turn against its creator. In E.T.A. Hoffmann's story *The Sandman* the protagonist falls in love with Olympia. Olympia is in fact an automaton created by the character Copolla who is a mysterious occultist. Nathanael, the protagonist of the story, was made to believe that Olympia is human and falls in love with her. This illusion is destroyed after her eyes are removed.

This story of Olympia and Nathanael served as an example in Ernst Jentsch's critical inception of the phenomenon of the uncanny in his essay "On the Psychology of The Uncanny" from 1906 (Jentsch, 1997). Jentsch described the uncanny as a status of cognitive dissonance or -how he coins it- as intellectual uncertainty as to whether "an apparently living being is animate and, conversely, doubt as to whether a lifeless object may in fact be animate" (Jentsch, 1997, p. 11). Thus, the source of Olympia's uncanniness was the uncertainty about her status as human or automaton. For Jentsch, this uncanniness of situations could also be observed outside of literature, for instance when encountering wax figures. Jentsch empathized that people differ greatly in their sensitivity to this feeling of uncanniness.

Sigmund Freud amplified on Jentsch's first explanations, because for him they were not exhaustive (Freud, 2003). Freud criticized that if the uncanny only resulted from intellectual uncertainty then "the better oriented he [a person] was in the world around him, the less likely he would be to find the objects and occurrences in it uncanny" (Freud, 2003, p. 125). For Freud the uncanny had other sources, mainly the recurrence of repressed infantile wishes, complexes and fears or in other words; something familiar has been repressed and when coming back it is both familiar and unfamiliar and therefore uncanny. However, Freud also acknowledged the importance of intellectual uncertainty as well as the factor of danger which is interwoven with fear and uncanniness. As a special case of recurrences Freud also mentioned the idea of the *doppelgänger*. According to Freud the double "was originally an insurance against the extinction of the self, or as Rank puts it, 'an energetic denial of the power of death', and it seems likely that the 'immortal' soul was the first double of the body" (Freud, 2003, p. 142). The meaning of the doppelgänger has, however, changed from being an "insurance of immortality to an uncanny harbinger of death" (Freud, 2003, p. 142). The fear that machines could replace humans was first picked out as a central theme by Karel Čapek in his play *R.U.R.* 'Rossum's Universal Robots' which premiered 1921. R.U.R. reflected deep-rooted anxieties towards the power of technology and picked out as central theme that those machines and robots replace human workers. Karel Čapek also introduced the neologism *robota* in this play which includes the meanings 'hard work' and 'slavery'. However, with his *Three Laws of Robotics*, Issac Asimov introduced a counterbalance to this fatalistic view on the future of robotics by restricting their power and framing them as predictable (Asimov, 1950).

The aforementioned observations have to be limited to Western cultures. While in Western culture, the overall positive attitudes towards artificial life changed during romanticism, Eastern cultures, for instance, did not undergo these radical changes. On the one hand, critical psychological regarding the uncanny or artificial life (cf. the work of Freud and Jentsch) did not the same attention in Asia as in Europe or the Americas. On the other hand, religious differences can explain at least partly the differences in attributions to robots or artificial life. For instance, in Christianity humans have been created in Gods image and thus human life is sacred and humans have a different standing than animals or nature. Therefore, the creation of artificial human life (in Gods image when it comes to android robots) is debatable. Moreover, Buddhism and Shintoism differ from Christianity in that these religious traditions also attribute spirits to things and not uniquely to humans.

Since the 1920s, robots and their advantages and risks have been core themes in numerous books and movies. It is however, difficult to define what a robot exactly is, as indicated by the introductory quotation by Masahiro Mori. A very interesting definition can be found in the Oxford Dictionary which classifies a robot in three ways: a) “a machine capable of carrying out a complex series of actions automatically, especially one programmable by a computer”, b) “(especially in science fiction) a machine resembling a human being and able to replicate certain human movements and functions automatically”, and c) “a person who behaves in a mechanical or unemotional manner”. Although a robot is still classified as a machine, it is clear that it differs from usual machines (otherwise a separate definition would be pointless) in certain ways. The most basic difference is that it performs automatically actions which are characterized by their complexity. The aspect of human-likeness is also of great importance. Moreover, humans which show inadequate behavior are ironically referred to as robots, because they act mechanically or unemotionally.

2. The uncanny valley – the theory and its history

In his article, *bukimi no tani*, Mori („Uncanny Valley“, Mori, 1970; Mori et al., 2012) warned his colleagues not to design robots which are too close to humans, because they would elicit a repulsive reaction. The original article was published in the Japanese journal “Energy”. Partial copies of this article circulated among researchers for a long time, but only recently a complete translated version authorized by Mori has been made available (Mori et al., 2012). Mori started with the observation that people tend to describe the relationship between any given two variables as monotonically increasing (i.e. linear) function and that people would react with confusion when they encountered a phenomenon which cannot be explained by this function. He stated that he observed something similar in the field of robotics with regard to people's affinity towards robots: "I have noticed that, in climbing toward the goal of making robots appear human, our affinity for them increases until we come to a valley, which I call the uncanny valley" (Mori et al., 2012). The model states that the more human-like robots become the more our affinity for these robots increases and we are more willing to accept them (cf. Figure 5). However, shortly before the ideal of perfect humanness is reached the curve dips and affinity reverses into uncanniness. Mori described this effect for still as well as for moving objects, although the effect is more pronounced when movement is involved. Mori explained these effects with an example: Imagine your interaction partner has a hand prosthesis. Indeed, nowadays good manufactured hand prostheses are hardly distinguishable from human hands, because they simulate fingers, nails and even finger prints, they do, however, lack the common temperature and the haptic of human tissue. Seeing this hand will trigger the schema of a human hand. But when you shake this hand it will not match up with the previously triggered expectations. The result is an eerie feeling. According to Mori, "in mathematical terms, this can be represented by a negative value. Therefore, in this case, the appearance of the prosthetic hand is quite human-like, but the level of affinity is negative, thus placing the hand near the bottom of the valley" (Mori et al., 2012, p. 98). If the hand was moving then this effect would be even stronger (cf. Figure 6). Mori also already introduced the question of realistic and unrealistic movement. He mentioned the example of a robot at the Expo 1970 in Osaka which showed facial displays simulating a smile. The designer showed how important dynamic sequences of facial deformations and the speed of these deformations are. When slowing down the smile, the robot did not look happy anymore, but creepy. Mori's answer to this phenomenon was an escape by design: "I predict it is possible to create a safe level of affinity by deliberately pursuing a nonhuman design." (Mori et al., 2012, p. 99). Mori also offered an explanation for the experience of uncanny feelings and that is the human instinct for self-preservation. Living humans are positioned on the second peak in Figure 6 (moving), but fall into the valley when they die (indicated by the dotted arrow in Figure 6 from the second peak into the (still) valley). This and other possible explanations will be discussed in more detail in section II.3.

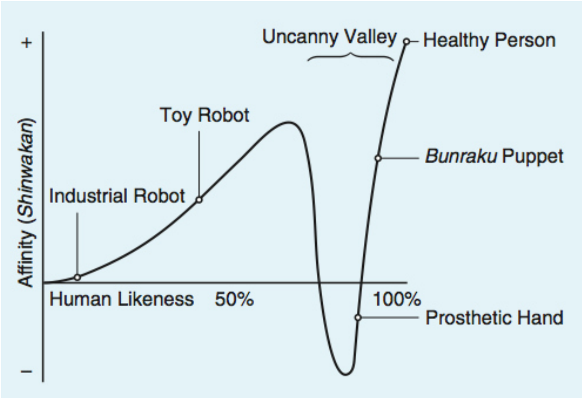


Figure 5: The graph depicts the uncanny valley, the proposed relation between the human-likeness of an entity and the perceiver's affinity for it. (Mori et al., 2012)

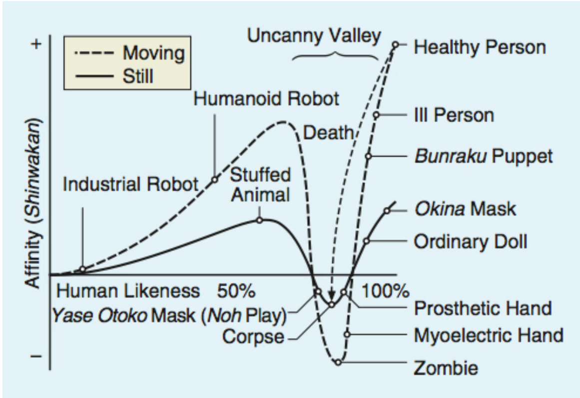


Figure 6: The presence of movement steepens the slopes of the uncanny valley. The arrow's path in the figure represents the sudden death of a healthy person. (Mori et al., 2012)

The translation of Mori's dimensions has long been controversial. The x-axis was sometimes represented as the dimension of human-likeness or as the dimension of anthropomorphism. For a long time, the y-axis has been translated as *familiarity*. The term familiarity certainly arose, because of its relatedness to the above discussed concept of the uncanny (cf. Freud, 2003; Jentsch, 1997) also referred to as the unfamiliar. Familiarity as dependent variable, however, seems unintuitive, since familiarity may change over time with repeated exposure as discussed by Bartneck and colleagues (Bartneck et al., 2007; Bartneck et al., 2009). Bartneck and colleagues discussed that Mori's original Japanese term *shinwa-kan* might be better translated as *affinity* or *likability* than familiarity. Indeed, the new translation of the original article also poses *affinity* as most appropriate translation for *shinwa-kan* (Mori et al., 2012). However, a lot of empirical work on the uncanny valley used the terms familiar and unfamiliar to investigate the uncanny valley effect (cf. section II.4).

In a recent interview Mori pointed out that at the time he started thinking about his hypothesis, there were no such (human-like) robots and that he "never imagined that it would gain such a magnitude of interest when I first wrote about it. Pointing out the existence of the uncanny valley was more of a piece of advice from me to people who design robots rather than a scientific statement." (M. Mori, personal communication, June, 12, 2012). This also explains the sketchy nature of this theory. For instance, it lacks precise definitions for human-likeness, affinity (or former familiarity). Mori himself stated in his original article that there is a need to build an accurate map of the uncanny valley. Although - or because - Mori's theory lacks precise definitions it is suitable for various applications. The concept has constituted itself in such a manner that developers think about how to avoid the uncanny valley before they start building a robot or an animated movie although nobody exactly knows how one can avoid the uncanny valley. Even prosthesis designers consider the uncanny valley in their design choices (Cabibihan et al., 2006). Despite the early introduction of the uncanny valley theory to scientific discourse, researchers mostly referred to it anecdotally as an explanation for their unexpected results (e.g. Hara, 2004, Walters, Dautenhahn, te Boekhorst, Koay, & Woods, 2007). Thus, since the 1970s, the uncanny valley has been an often-cited explanation in robot science, although barely been tested empirically. In contrast, the research field of computer graphics discussed the uncanny valley much earlier than the field of robotics and also started to empirically investigate the uncanny valley (cf. section II.4). With the movies *Polar Express*, *Final Fantasy* and *The Incredibles* the term uncanny valley also entered public discourse (e.g. Canemaker, 2004; Loder, 2004; Mangan, 2007). While *Polar Express* and *Final Fantasy* were referred to as bad examples in which characters showed a mismatch between appearance and behavior, *The Incredibles* were praised as a good example demonstrating that cartoonlike characters can be perceived as more natural and lifelike.

The observations of the moviemakers on the reception of their movies and the anecdotal evidence from robotic research indeed suggest that something like the uncanny valley might exist, but they surely did not contribute to the clarification of the origins of this phenomenon. However, starting in the year 2005 robot scientists have set about the task of investigating the uncanny valley more systematically.

The following section will review the proposed explanations for the uncanny valley effect and introduce critique on the hypothesis and revised models. Afterwards empirical evidence regarding the (non-)existence of the uncanny valley will be presented as well as investigations with regard to the proposed explanations and other related concepts.

3. Proposed explanations for the uncanny valley effect and revised models

This section reviews possible explanations for the uncanny valley effect proposed by different scholars. The author roughly classified the proposed explanations as perception-oriented approaches, evolutionary-biological approaches, and cognitive-oriented approaches. Moreover, this section includes an overview of critique on and revised models of the uncanny valley hypothesis.

3.1 Perception-oriented approaches

With regard to the perception-oriented approaches, MacDorman and Ishiguro (2006) identified different explanations for the uncanny valley, for instance, the *violation of previously triggered expectations*. In this context, Cowley and MacDorman (2006) emphasized the importance of nature norms and interactional social norms. A nature norm is, for example, the average body temperature of 36 °C and the texture of human tissue, but also the tasks an organ fulfills (e.g. heart is responsible for blood circulation). Furthermore, there are interactional and social norms. What all these norms have in common is that alongside with their establishment also a control system is implemented by which the compliance with the norm can be measured. Thus, it can be concluded that there is no idiosyncratic behavior. Each movement and each action is either epistemic (and serves to gain knowledge) or social (and serves as information source for others). Actions are subject to so manifold norms that any movement or any failure in moving is followed by a norm based evaluation. However, androids often violate the expectations of their human interaction partner. This triggering and violating of norms can occur across different modalities and include various perceptual and sensorimotor processes.

A very similar explanation has been proposed by Bartneck, Kanda, Ishiguro, and Hagita (2007) who referred to Minsky's framing theory (Minsky, 1975) which explains that we organize knowledge on previous experiences with stereotyped situations in so-called frames. Bartneck et al. stated that when people encounter a machine-like robot they would select a "machine frame". They proposed that the human-like features this robot has would deviate from the expectations, but would attract attention, because humans tend to like other humans. However, when people would meet an android robot, they would select a "human frame". Again the deviations from the expectations - in this case machine-like features - would attract attention. Only in this case, these deviations would be disturbing.

Saygin, Chaminade, Ishiguro, Driver and Frith (2012) discussed the so-called *prediction error* as a framework that may contribute to the explanation of the uncanny valley. Similarly to the above presented explanations, Saygin et al. proposed that the appearance of an entity leads to predictions of adequate movement for this entity. When the observed entity shows inadequate movement (e.g. a robot with human-like appearance shows mechanical behavior), the result is a prediction error leading to increased brain activity which is subsequently negatively interpreted.

That *conflicting perceptual cues* not only of movement and appearance, but also of different aspects of appearance (like surface structure) could be the cause of negative emotional reactions has been shown using diverse methodologies and stimulus material (Burleigh et al., 2013; Cheetham, Pavlovic, Jordan, Suter, & Jancke, 2013; Cheetham, Suter, & Jäncke, 2011; MacDorman et al., 2009; Saygin et al., 2012). Moreover, MacDorman stated in an interview about the uncanny valley (K.F. MacDorman, personal communication, December 21, 2007) that a variation of the degree of anthropomorphism not only includes the appearance, but also other senses like touch or the smell of a human. He also mentioned dynamic aspects like the quality of movement, speech, prosody, the quality of the voice and aspects of continuity like interactivity and timing. Thus it can be assumed that conflicts of perceptual cues can occur across diverse modalities.

3.2 Evolutionary-biological approaches

MacDorman and Ishiguro (2006) also presented approaches with origins in evolutionary biology. The authors referred to Rozin's theory of disgust (Rozin & Fallon, 1987; Rozin, Haidt, McCauley, Lance Dunlop, & Ashmore, 1999). Disgust is described as an evolutionary developed cognitive mechanism to *avoid the risk of infection* and the risk of *genetically inadequate mating partners*. Genetically similar organisms contain the risk of transferring diseases. Therefore, organisms with completely different genes are not disgusting and neither are healthy exemplars of the own species. However, "The more human an organism looks, the stronger the aversion to its defects, because (1) defects indicate disease, (2) more human-looking organisms are more closely related to human beings genetically, and (3) the probability of contracting disease-causing bacteria, viruses, and other parasites increases with genetic similarity." (MacDorman et al., 2009, p. 696). Disgust is a mechanism that serves different purposes (e.g. avoid toxins, avoid infections, avoid compromising reproductive fitness, avoid unsustainable interaction partner) and thus responds to very diverse superficial cues such as unpleasant tastes and odors (e.g. rotten smells, bitter tastes), the sight of vomit, feces, and blood. But disgust is also observable as reaction towards bodily deformities, contact with unfamiliar individuals, and violation of social and moral norms (Chapman & Anderson, 2012). It has been described that the disgust mechanism is based on a cost-benefit function which is tuned to minimize false-negatives with the cost of high false-positives. Accordingly, the mechanism is characterized by a certain oversensitivity which can result in aversive responses to things (including people) that pose no actual threat of pathogen infection (Schaller & Park, 2011) such as people with physical disabilities (e.g., limb amputation due to accident; Park, Faulkner, & Schaller, 2003 or people suffering from obesity

Park, Schaller, & Crandall, 2007). Robots, and android robot in particular, closely resemble human beings. Since it has been shown that human “rules” of physical attractiveness are also applied when judging the attractiveness virtual agents, similar mechanisms can presumably be observed for android robots. Thus, it can be assumed that androids are uncanny to the extent to which they differ from the nature norm of physical attractiveness (MacDorman & Ishiguro, 2006) and to the extent to which they provide superficial cues that elicit disgust reactions. MacDorman and Ishiguro discuss that these mechanisms would lead to the hypothesis that uncanny robots elicit an innate fear of death and thereby increase the *salience of one’s own mortality*. In this regard, humans are the only beings that are aware that they are mortal, because humans are self-conscious and are able of temporal thought (Solomon, Greenberg, Schimel, Arndt, & Pyszczynski, 2004). Connected to the realization of one’s own mortality is the realization of actual threat: “As a naked fact, that realization is unacceptable....Nothing, perhaps, is more comprehensible than that people--savage or civilized--would rather reject than accept the idea of death as an inevitable close of their brief earthly careers.” (Langer, 1982, p. 87). It has been argued that culture originated also to cope with this threat (e.g. Becker, 1997; Solomon et al., 2004). Hence, when human beings are confronted with their mortality and their vulnerability to death, the emerging feelings of terror elicit defense reactions one of which can be the elevation of one’s own culture. This phenomenon is also known as terror management and has been extensively researched (e.g. Greenberg et al., 1990). With regard to the uncanny valley, MacDorman and Ishiguro (2006) argue that android robots elicit human’s fear of being mortal and thus uncanny valley related reactions can be interpreted as defense reactions to cope with this anxiety.

3.3 Cognitive-oriented approaches

Similarly to the above presented explanation that conflicting perceptual cues elicit negative emotional responses, Ramey (Ramey, 2005; Ramey, 2006) argued that the uncanny valley results from *uncertainty at category boundaries*. However, for Ramey this effect is not exclusive to the field of humanoid robotics, but the uncanny valley effect is rather “a member of a class of cognitive and perceptual states of uncertainty at category boundaries (i.e., humans and robots) for a novel stimulus (i.e., human-like android).” (Ramey, 2006, p. 21). In contrast to the above mentioned approaches, according to Ramey, category boundaries are not static. Thus, there is the possibility that humans form a third category concerning humanoid robots through repeated contact which would solve the dilemma.

Furthermore, Ramey (Ramey, 2005) mentioned as explanation *sorites paradoxes involving personal and human identity*. Sorites paradoxes relate to a form of little-by-little arguments which lead to an apparently false conclusion. The sorite paradoxon is often explained using the heap example: the definition of a heap lacks sharp boundaries as to there is no number of grains of sand which are defined as forming a heap. When we now say that a given number of grains of sand do not make a heap and adding an additional grain does not make a heap either, then to conclude that no additional amount of sand will make a heap is to construct a sorites argument. Thus an uncanny valley effect can also occur for other things that gradually change into something different. With regard to the uncanny valley effect for humanoid and android robots it could be caused by the linkage of two qualitatively distinct categories (human vs. robot) by a quantitative metric (i.e. degree of human-likeness) that undermines their original separation.

Moreover, alongside the mortality salience introduced above, MacDorman and Ishiguro (2006) also mentioned other aspects of androids which might trigger *subconscious fears of reduction, replacement, and annihilation*. For instance, disassembled androids could be reminiscent of a battlefield after a conflict and thus remind us of our own mortality. The knowledge that behind the human appearance hides a mechanical interior might trigger the fear that we are all just soulless machines. As already mentioned in section II.1 most actually available android robots are doppelgänger of real people and may elicit the fear of being replaced. Moreover, MacDorman and Ishiguro said that our fear of losing bodily control might be triggered by the jerkiness of an android’s movement.

3.4 Critique and revised models of the uncanny valley theory

Based on observations of the positive reception of very realistic depictions of humans in arts, Hanson Olney, Pereira, and Zielke (2005) criticized the general tendency of roboticists to avoid very human-like robots. In their view “any level of realism can be engaging if one designs the aesthetic well” (Hanson et al., 2005, p. 30) and they thus introduced a revised theory which they call *Path of Engagement*. Elaborating on this theory, Hanson et al. explained that when people get more sensitive with increasing levels of realism this does not necessarily imply a negative reaction. While some realistic (robotic) faces that behave strangely might trigger survival reflexes, others might trigger more surreal feelings and with surreal, Hanson et al. refer to dreamlike, i.e. positive feelings. The latter might be achieved by considering aesthetics while developing human-like robots. However, the authors also emphasized the need to explore the uncanny valley in order to find the *Path of Engagement*.

In his review article on the uncanny valley, Pollick (2010) followed a thread opened by Ramey and looks at the uncanny valley from a different viewpoint which is how normal human activity might be modulated to fall into the uncanny valley. Pollick first summarized previous work on the uncanny valley and proposed a working definition describing the uncanny valley as “a phenomenon that exists in the stimulus space around normal human activity and is triggered from either perceptual mismatches or categorical effects, but that the critical level of evaluation might be social.” (Pollick, 2010, p. 74). He acknowledged that this working definition avoids precise definitions of the corresponding dimensions of realism and affinity and claims that these would be best addressed through empirical investigations. Subsequently he elaborated on the examples of dubbed speech, the fear of clowns and the Capgras syndrome (people with this disorder believe that other people have been replaced by duplicates) starting from the right side of the uncanny valley curve moving towards the uncanny valley. Considering dubbed speech, it apparently illustrates a perceptual mismatch between an actual human movement and an actual auditory signal leaving the question why this mismatch does not necessarily elicit an uncanny valley effect. Perhaps there has been an uncanny valley effect, since research showed that children prefer subtitled programs over dubbed programs (Koolstra, Peeters, & Spinhof, 2002). Pollick concluded that dubbed speech might be an example where habituation was able to overcome a natural tendency to find the experience unpleasant (at least in media markets which make frequent use of dubbed programs, such as Germany). With regard to the perception of clowns, Pollick pointed out that clowns are undeniably humans (with painted faces), yet there are possible perceptual inconsistencies with regard to the painted facial expression and the performed actions which might be the cause of clown phobia. The last example of the Capgras syndrome (Ellis, Whitley, & Luaute, 1994; Ellis & Lewis, 2001) exemplified that an uncanny situation can occur in absence of any perceptual inconsistencies. Patients suffering from Capgras syndrome are convinced that people in their surroundings have been replaced by duplicates. While patients rationally accept that these duplicates are physically identical, they irrationally believe that the true entity has been replaced by something else which naturally is unsettling for the patients. In these examples Pollick saw support for his view that the uncanny valley can arise “from issues of categorical perception that are particular to the specific way the social brain processes information” (Pollick, 2010, p. 76) and thus showed that they are deviations from normal human behavior and normal human recognition which would fall under the definition of the uncanny valley effect.

Based on the hypothesis that humans expect balance between appearance and behavior when they recognize creatures, Ishiguro (2006) assumed a synergy effect for those cases where appearance and behavior are well-balanced. By matching the graphs of both hypotheses, namely the uncanny valley and the synergy effect, Ishiguro created an extended graph of the uncanny valley, cf. Figure 7. Surprisingly, Ishiguro assumed the synergy effect to be a linear relationship between similarity of appearance and similarity of behavior, although there are striking arguments against this assumption. First, there are computer programs like Eliza (Weizenbaum, 1966) which show to some extent human-like behavior (although only verbal behavior and no motion), but which are only represented by text input and output on a screen. Moreover, there are examples of robots in the media which are highly intelligent and capable of human-like behavior such as engaging in conversations, caring for fellows, making moral decisions, yet having no similarity in appearance at all, like the robotic car K.I.T.T. in Knight Rider. Both examples are certainly not known to elicit uncanniness, nor do they fit into the suggested linear relationship. It is possible that Ishiguro refers to solely “bodily” behavior, i.e. human-like movement. This is, however, unsound given Ishiguro’s further explanations that certain behaviors imply certain cognitive processes (e.g. eye movement is a way of representing thinking). Altogether, the proposed extended uncanny valley is inconclusive. However, Ishiguro also mentioned other aspects which contribute to a more critical view on the uncanny valley effect. He reported about his observation that one-year-old babies were attracted by a child android which otherwise totally put off three and five-year-old children. Ishiguro suggests an age-dependent uncanny valley and explains his results with different developmental states. Because the babies’ model of others is poorly developed and adults’ can explain by their knowledge that an android cannot fit their expectations of a human model, neither react with fear. However, young children have learned to apply human models and started to be sensitive for mismatches.

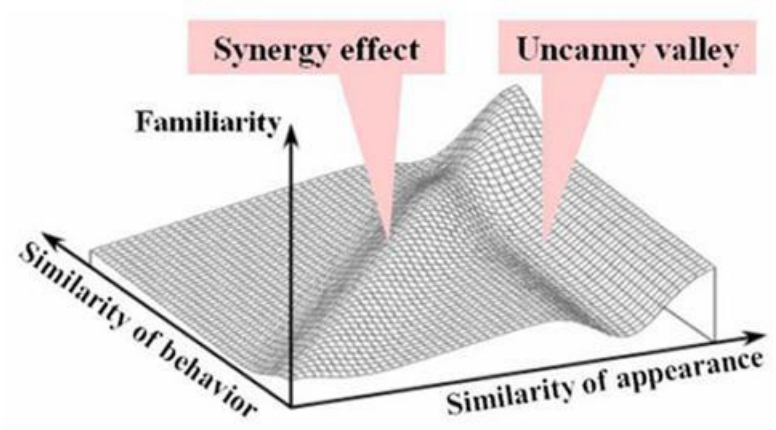


Figure 7: Extended uncanny valley (Ishiguro, 2006, p. 6)

Based on their findings from comparing pictures of humans, robots and faces, Bartneck et al. (Bartneck et al., 2007) hypothesize an alternative model for the uncanniness of robots. The results of their study revealed the participants evaluated toy robots and humanoid robots as most likable, even more likable than humans. Thus they regard the uncanny valley rather as an uncanny cliff (cf. Figure 8) and state that it would be unwise to develop androids, since they would be less liked than machine-like robots.

In a later paper by Bartneck, Kanda, Ishiguro, and Hagita (2009) the authors emphasize that Mori's hypothesis of the uncanny valley is too simplistic. Since movement also contains social meanings it may have direct influence of the likability of a robot. Moreover, anthropomorphism is not only conditioned by mere appearance, but also by behavior. They conclude that "a mechanical-looking robot with appropriate social behavior can be anthropomorphized for different reasons than a highly human-like android." (Bartneck et al., 2009, p. 275).

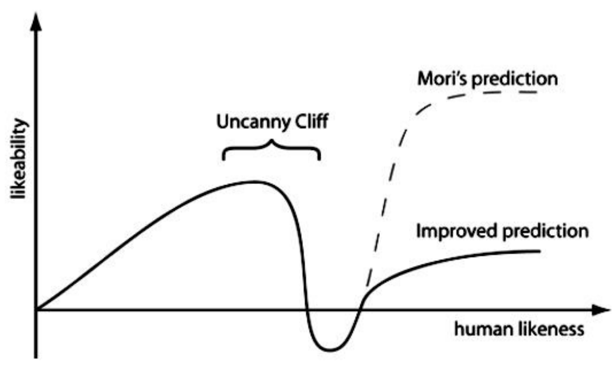


Figure 8: Hypothesized uncanny cliff (Bartneck et al., 2007, p. 373)

Bartneck et al. state that it is generally desirable to have simple models as long as they have explanatory power, a criterion which they deny that Mori's model has. The authors speculate that the theory's popularity stems from the "escape route" it offers, since the uncanny valley makes it easy for designers of robots or screen-based agents to attribute negative impressions to the evaluating user instead of to the shortcomings of the particular robot or agent. In contrast to using it as an escape route, Bartneck et al. point out that it might be better used as benchmark so as to use negative impressions as feedback for further improving robots.

Brenton, Gillies, Ballin and Chatting (2005) propose that the uncanny valley response could be culturally dynamic and be subject to change over time. The influence of habituation and culture has also been discussed by Gee, Browne and Kawamura (2005) alongside with the influence of the age of the test subjects, their religion and the appearance and the size of robots. Some of these points have already been introduced above, religion and culture, however, are new aspects. Gee et al. assume that culture may affect people's responses to robots, depending on how robots are presented in the media. The authors exemplify that in Japan robots are generally presented as "good", whereas robots in western cultures are generally presented as "bad" entities. Moreover, Buddhism and Shintoism differ from Christianity in that these religious traditions also attribute spirits to things and not uniquely to humans.

3.5 Summary

In conclusion, a number of explanations for the uncanny valley effect have been proposed. Based on the literature these explanations have been classified three categories: perception-oriented, evolutionary-biological oriented and cognitive-oriented explanations. The first category addresses explanations on the level of perception and direct cognition, regardless of how they are named (violation of previously triggered expectations, prediction error, conflicting perceptual cues). All explanations refer to the process that one perceptual cue (most often appearance) elicits predictions about the quality of other perceptual cues. These cues can range from the general description of "behavior", but in some proposals has been broken down to diverse aspects like fluentness of movement or speech, timing, or the social meaning of movement. While this process is robust to failures for distinct categories of entities, it leads to uncertainty for entities which are at the boundaries between (neighboring) categories. This uncertainty is expected to be interpreted as negative and thus the cause of the uncanny valley response. Some scholars explicitly point out that this uncertainty can also arise for any other conflicting perceptual cues or for any other entities at category boundaries, not necessarily only for humanoid or android robots and humans (Bartneck et al., 2007; Saygin et al., 2012; Ramey, 2005, Ramey, 2006). Secondly, this uncertainty at category boundaries becomes a hot potato when the category "human" is involved, because humans' sensitivity to perceptual mismatches regarding fellow humans follows evolutionary exigencies like pathogen avoidance and mate selection which are explanations subsumed under the second category of evolutionary-biological approaches. It is assumed that uncanny valley effects are due to an oversensitivity bias of the behavioral immune system which responds to an overly general set of superficial cues. Consequently, things and people can elicit aversive responses although they pose no actual threat of pathogen infection (Schaller & Park, 2011). Thirdly, there are explanative approaches which address how humans explain, construct and defend their identity as human beings. The manifold approaches to explain the uncanny valley effect underline the complexity of the underlying mechanisms. Thus, it is not surprising that Mori's theory is consistently criticized as being too simplistic, that its dimensions are not defined enough (Bartneck et al., 2007; Bartneck et al., 2009; Pollick, 2010; Gee et al., 2005) -especially because they, too, are complex dimensions- and that it neglects other relevant factors besides inherent characteristics of the robots under investigation such as participants' age, culture, religion, or their previous experiences (Gee et al., 2005; Brenton et al., 2005; Ishiguro, 2006).

4. Empirical work on the uncanny valley

This section reviews empirical work on the uncanny valley hypothesis. Section II.4.1 summarizes studies attempting to show the existence or non-existence of the uncanny valley. Since android robots are considered to fall into the uncanny valley, there exists some empirical research in human-robot interaction with androids concentrating on the uncanny valley hypothesis. This work will be presented in section II.4.2. Most recent research on the uncanny valley addresses possible explanations. This and related work as well as more information on the underlying concepts are introduced and discussed in section II.4.3. Section II.4.4 is concerned with empirical work and concepts related to the uncanny valley such as appearance, anthropomorphism, and narration. This section closes with a short review on cultural differences in the perception and acceptance of robots in section II.4.5.

4.1 Studies showing the (non-) existence of the uncanny valley

Early work on the uncanny valley hypothesis tried to emulate the uncanny valley graph using pictures or videos of robots. In order to prove the existence of the uncanny valley effect, MacDorman and Ishiguro (2006) investigated peoples' reactions towards morphed pictures on a continuum from *mechanical robot* to *humanoid robot* to *human* (cf. Figure 9). Indeed, results showed that at the threshold between mechanical and humanoid robot the perception of *uncanniness* increased, *familiarity* decreased and the picture was also rated as less *human-like*. Admittedly, these results were relativized by Hanson (2006) who repeated the study based on the same stimulus material (the same mechanical robot, the same human person) but created two different sets of morphs: the first set was identical to MacDorman and Ishiguro's study, the second set comprised morphs which were more attractive (cf. Figure 10). While for the first set the previous results of MacDorman and Ishiguro could be replicated, there was no uncanny valley effect for the more attractive morphs. Hanson concluded that the uncanny valley and the connected negative reactions can be avoided by clever manipulation of the appearance. As discussed by Bartneck et al. (2007) the method of using morphed pictures appears useful, because there are not that many different human-like or even android robots available. However, it seems difficult to produce meaningful blends between humans and robots resulting in pictures in which clearly two pictures are superimposed. Given that, it is not surprising that these pictures are rated as eerie. Moreover, MacDorman and Ishiguro as well as Hanson used a very simple approach to measure the related concepts. Participants rated human-likeness, familiarity and eeriness on one item each. The results are only descriptive and presented as plots of the average ratings without any testing of significance.

Figure 9: Morphs used in the study by MacDorman & Ishiguro (2006, p. 305)

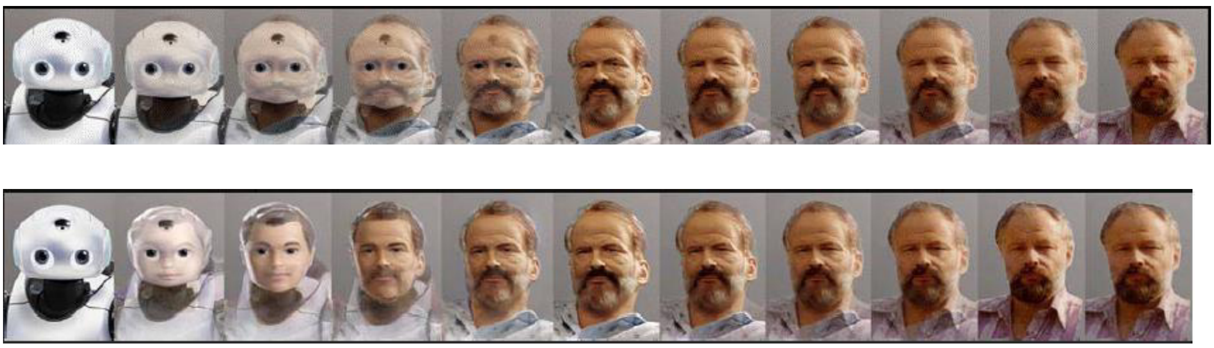


Figure 10: Above the replicated "uncanny" morphs, below the more attractive morphs used in the study by Hanson (2006, p. 19)

Similarly to these two studies, Hanson et al. (2005) also used pictures in which a woman is morphed into a female cartoon character. Here participants were asked to rank the pictures as either acceptable or unacceptable. Percentages of acceptance were reported showing that all pictures were accepted by around 80 percent of the participants. Hanson et al. again conclude that considering rules of aesthetics can extinguish the uncanny valley effect. Lay (2006) also used morphs to plot the uncanny valley. In her study the original pictures were a computer generated face and a human woman. Participants were asked for their emotional response via a list of emotional terms. The overall positive and overall negative emotion scores were plotted against human-likeness resulting in a "fluctuation away from a linear trend in both positive and negative emotion." (Lay, 2013, "Rating Faces", para. 5). However, also these results are only descriptive.

As already mentioned above, Bartneck et al. (2007) criticized that morphing of pictures may result in very unrealistic stimuli in which aspects of both original pictures are superimposed. They suggest to using computer-generated faces or pictures of human faces which were slightly modified, especially to address the right part of Mori's graph from the dip of the valley up to the healthy human. Thus, in their attempt to plot the uncanny valley Bartneck et al. used not only pictures of faces of real humans and androids, but also manipulated humans and computer graphics of humans. Moreover, all pictures were framed in three different ways in order to examine whether the framing as a robot has a positive influence on the likability ratings of androids. Thus, all pictures either presented as being human, or robot, or simply neutrally as a face. Results showed, however, that framing had no effect at all leading to Barneck et al.'s conclusion that "a highly human-like android is not uncanny because of the fact it is a robot, but because of its appearance." (Bartneck et al., 2007, p. 372).The authors also propose that the uncanny valley is rather an uncanny cliff building on their observation that likability ratings where highest for the humanoid and pet robots, even higher than for real humans (cf. also section II.3.4). Furthermore, those studies examining the proposed explanations of category uncertainty and conflicting perceptual cues which used virtual faces suggest that the uncanny valley also exists for virtual agents (Burleigh et al., 2013; Cheetham et al., 2013; Cheetham et al., 2011; Green, MacDorman, Chin-Chang, & Vasudevan, 2008; MacDorman et al., 2009; Seyama & Nagayama, 2007; Seyama & Nagayama, 2009). These studies will be discussed in more detail in section II.4.3.1.

However, the results of these experiments reflect only one side of the uncanny valley, those of the non-animated subjects and should be extended to also address robotic movement. Consecutively, it has been investigated whether the uncanny valley effect also occurs (and maybe even stronger) while presenting animated stimuli. MacDorman (2006) conducted a study in which participants rated 14 videos of various robots with regard to their human-likeness, their familiarity and their eeriness. The set of videos contained two control videos (a human and an industrial robot arm) and 12 videos of predominantly humanoid and android robots which were filmed in different settings fulfilling different tasks. Results did not show a clear uncanny valley effect on the continuum human-likeness in that the data did not reproduce the uncanny valley graph. The author concluded that the alikeness to a human is just one of many factors determining the perception of a robot as human-like, familiar or even uncanny. MacDorman saw this result as an indicator that the uncanny valley can be overcome by the manipulation of these other factors (e.g. movement). In contrast to the morphed pictures in previous studies which presented themselves in a consistently gradient change the videos differed extremely with regard to setting, tasks the robots fulfilled, accompanying sound and speech output, respectively. The variation of these additional factors (movement, tasks, setting, speech output) could thus overcome the uncanny valley, which was reported as in line with the results of Hanson's study (2006) in which the uncanny valley effect was extinguished by the manipulation of attractiveness.

Ho, MacDorman and Pramono (2008) replicated this study based on the evaluation of videos, but concentrated on the assessment of the participants' emotions. In contrast to the previous study, the authors used more comparable videos which did not include sound and showed predominantly the head of the robots. In addition to the typical uncanny valley related items (e.g. "The figure looks strange/eerie/creepy/human-like.") participants were supposed to report their emotional state (e.g. "The robot makes me feel disgusted."). The goal was to investigate which emotional statements are connected with the attributes creepy, strange and eerie during the perception of robots, to which extent these terms are routed within early perceptual or later cognitive information processing and which of these attributions - creepy, eerie, strange are most appropriate to describe uncanny robots. As a result the authors conclude that eerie and creepy are more appropriate than strange to describe the uncanny valley phenomenon. Moreover, they state that fear is highly predictive for eerie and creepy. The authors conclude that their results cannot rule out one of the two focused explanations (fear of own mortality, mechanism for pathogen avoidance) and frame the uncanny valley as "nexus of phenomena with disparate causes" (p.175).

Also working with video clips but of virtual characters instead of robots, Thompson, Trafton, and McKnight (2011) parametrically manipulated three different kinematic features of two walking avatars and found that, contrary to the uncanny valley hypothesis, ratings of the humanness, familiarity, and eeriness of these avatars changed monotonically.

A further study which used video clips to investigate the uncanny valley was presented by Riek, Rabinowitch, Chakrabartiz, and Robinson (2009). Riek et al. hypothesized that humans will empathize more along the anthropomorphic spectrum. In this web-based study participants saw a neutral and an emotional video of a robot; in the latter one the robot was either verbally or physically abused. The stimulus material contained videos of two mechanical robots (Roomba, AUR), two humanoid/android robots (Andrew from the movie “Bicentennial Man” and Alicia from “Twilight Zone”) and one human boy (Anton from the movie “The 400 Blows”). Participants experienced significantly more empathy with the two humanoid robots Andrew and Alicia than with the mechanical looking robots. Furthermore, they indicated that they would be more likely to rescue them during an earthquake than the mechanical robots. Also in this study the movies varied in setting and type of abuse. In addition, the human as well as the humanoid/android robots were movie characters whereas the mechanical looking robots were real robots. The participants could therefore have addressed their empathetic feelings to the known actor of the movie character.

A different measure to examine uncanny responses was applied by McDonnell and Breidt (2010) who measured how trustworthy different appearances of virtual characters were perceived by their participants. Motion captured interaction sequences of an actor telling truths and lies were applied onto a virtual model and rendered in three different qualities. Participants had to decide for each video whether the character is telling a truth or a lie and indicate their confidence level for the decision. MacDonnel and Breidt found that sequences rendered in high quality were rated significantly more often as ‘lie’ than sequences in a non-photorealistic rendering style regardless of participants’ self-reported trustworthiness ratings for all the characters or their accuracy for detecting truths and lies neither of which differed across conditions. The authors argue that this might be due to subtle cues being easier to detect in high quality rendering than in non-photorealistic rendering.

A very interesting approach to investigating uncanny reactions has been applied by Tinwell and colleagues. The research group tried to identify those character qualities which are perceived as being eerie, to develop design guidelines for eerie characters in survival horror games. Tinwell and Grimshaw (2009) asked participants to rate fifteen video clips of different virtual characters and one human with regard to how human-like the character looks, how strange/familiar the character is and how human-like the voice of the character sounds. The virtual characters included six photo-realistic characters, six zombie characters and three stylized human-like characters including a chatbot, Lara Croft (video game Tomb raider) and Mario (video game Super Mario). Participants rated the videos of the characters with regard to their human-likeness, eeriness and with regard to the adequateness of the shown behavior (in relation to the character's appearance). Additionally, participants' level of experience in both playing video games and using 3D modeling software was assessed. By plotting the eeriness-familiarity ratings against the human-likeness ratings Tinwell and Grimshaw conclude that their results show more than one uncanny valley. However, these valleys seem to be a product of two outliers, Super Mario and Lara Croft, which received very high familiarity ratings, but in the case of Super Mario a low human-likeness rating. Since both characters are a) extremely popular and b) cute or beautiful in their appearance, respectively, they constitute quite a contrast to the overall sample. Moreover, the plotting of these results is again, as in previous studies, only a descriptive presentation of results. Consequently, the authors state that perceived familiarity is dependent upon a wider range of variables other than solely appearance and behavior which is plausible regarding the influence of the well-known outliers Super Mario and Lara Croft. Tinwell and Grimshaw further dispute that the uncanny valley phenomenon can be resolved by a habituation effect, since those participants with experience of 3d characters showed no great differences in their evaluations. Based on the same data set, but obviously excluding the ratings for Super Mario and Lara Croft, Tinwell, Grimshaw, and Williams (2010) report results concerning the interplay of appearance, motion and sound. Participants were to evaluate whether the voice is okay or too slow, monotone, of wrong pitch/intonation, or seems to belong to another character. Moreover, they could indicate certain facial regions which appeared to have either an exaggerated or a lack of facial expression. Finally, participants had to evaluate the quality of lip synchronization. The authors found strong correlations between perceived strangeness of a character and the human-likeness of its voice, human-likeness of its facial expression, and perceived quality of lip-synchronization. However, it has to be mentioned that half of the characters used in this study were especially designed to look like zombies and thus have a special ugly and disgusting appearance which is quite opposite to the rather polished designs of robots or the usual virtual characters in games.

Altogether, the results are inconclusive, because there is as much evidence for the existence of the uncanny valley effect, as there is for its non-existence. The studies used varying approaches to show an uncanny valley effect, including morphed pictures, pictures of actual humans, robots and computer graphics as well as videos of actual robots. Moreover, most of the studies have methodological shortcomings and use, for instance, non-standardized material (MacDorman, 2006; Riek et al., 2009), a very limited set of stimuli (Bartneck et al., 2007; Riek et al., 2009), or used single items to account for probably complex concepts like human-likeness, eeriness or familiarity (e.g., Hanson, 2006; Hanson et al., 2005; Lay, 2006; MacDorman & Ishiguro, 2006; Riek et al., 2009; Tinwell & Grimshaw, 2009). For early studies, only descriptive results were reported (Hanson, 2006; Hanson et al., 2005; Lay, 2006; MacDorman & Ishiguro, 2006; Tinwell & Grimshaw, 2009). Also, it has to be acknowledged that all these studies only examined short-term reactions to potentially fictional material leaving the question open as to whether the uncanny valley effect, if it really exists, is maybe just a short-term reaction. In addition, no conclusions can be drawn on peoples' experiences in interactions with real robots. However, this work also identified other relevant factors for the uncanny valley effect, such as aesthetics, sound, timing, and context.

4.2 Studies featuring interactions with androids

In addition to the use of pictures and videos android robots were also used in laboratory experiments to investigate different aspects of the uncanny valley. Besides anecdotal observations, there are studies addressing the influence of movement by varying different degrees of movement or appearance by including different types of robots and androids, or by changing the appearance of an android (cf. Figure 11 for examples of android robots).

Figure 11: Examples of android robots (from left to right): Repliee Q1, Geminoid HI-1, Repliee R-1

Ishiguro (2006) reports about anecdotal observations during a study involving infants (cf. Section II.3.4 and Itakura, Kanaya, Shimada, Minato, & Ishiguro, 2004). He observed that one-year old babies were attracted by a child android which otherwise totally put off three and five year old children. He explains the results with different developmental states and thus suggests an age-dependent uncanny valley.

In a study by Noma, Saiwaki, Itakura, and Ishiguro (2006) participants were confronted with an android in what the authors call a Total Turing Test (Turing, 1950, French, 1990, French, 1990). Participants saw a human woman or the female android ReplieeQ2 (looks like a Japanese woman in her thirties, cf. Figure 11) showing either no movement (static condition) or natural movements. Participants were exposed to one of these conditions for either one or two seconds and were asked whether they saw a human or a robot. Not surprisingly the human woman was identified as human most often, followed by the moving android and the static android. Moreover, the fellow human was rated as significantly more human-like than the static android, while there was no significant difference between human and moving android. The authors see this as an indicator that movement contributes to the human-likeness of the android. The displayed behaviors were, however, still very limited, because they imitated a human sitting naturally. In addition, the authors discuss that the idea of a Total Turing Test is that people are not able to distinguish between human and machine on the basis of a longer interaction. In this study, the exposure time was very short, thus, longer exposure could elicit different effects.

In order to examine the influence of motion on the uncanny valley effect, Minato, Shimada, Ishiguro, and Itakura (2004) used eye tracking data of participants in interaction with a human girl, a child-sized android with eye, mouth, and neck motions, and a child-sized android which did not move except for lip-synchrony of speech in a within-subject study (Repliee R-1; cf. Figure 11). The results show differences in participants gaze behavior. In both android conditions participants looked more frequently at the android's eyes compared to the human girl's eyes. The authors regard this as remarkable, since Japanese people tend to avoid eye contact owing to cultural reasons. However, many subjects perceived the android's appearance and movement to be artificial and Minato et al. argue that subjects might have tried to achieve mutual understanding by increased eye-contact. Contrary to the authors' prediction, there was no significant difference between the two android conditions.

Subsequent studies concentrated on gaze aversion instead of fixation. Building on the assumption from social signal theory that people break eye contact to inform others that they are thinking, the group of researchers around Minato, Shimada and Ishiguro expected gaze aversion to be influenced by the human-likeness of the interlocutor and thus gaze aversion could serve as a measure of human-likeness of robots in future studies. In a first study, Shimada, Minato, Itakura, and Ishiguro (2006) compared people's gaze aversion in interaction with a human, the android Repliee Q2 (female android, Japanese woman in her thirties) and the mechanical robot Eveliee P1 during a question-answer game with questions which could be easily answered ("know"-questions) and questions where participant's had to think about their answers ("think"-questions). It was analyzed how long in percentage participants averted gaze in a specific direction (up, down, left, right, upper left, upper right, down left, down right). As expected, participants showed less gaze aversion during the know-questions compared to the think-questions. Moreover, there was a difference between the directions of gaze aversion across conditions. Participants predominantly averted gaze by looking down when interacting with the mechanical robot. When interacting with a human or the android robot, they averted gaze predominantly by looking to the side. In this study, the experimenters tried to keep the behavior of the human and android as consistent as possible. In a follow-up study by Shimada and Ishiguro (2008) the behavior of an android robot was varied in several ways in order to examine the influence of behavior on the unconscious perception of human-likeness measured by gaze aversion. Shimada and Ishiguro used the same procedure. This time, the android Repliee Q2 displayed different levels of human-like movement: human-like movement (blinking, movement of eyes, mouth, breathing, subtle changes in posture (waist, neck, shoulders)), robot-like movement (no blinking, all other movements were displayed using fewer degrees of freedom than in the human-like condition), "in-between" movement (parameters from human-like and robot-like movement were averaged), or no movement at all. In two more conditions isolated aspects of movement were deactivated: eye movement and waist movement, respectively. By deactivating these aspects of movements, the authors wanted to explore how much each of these aspects contributes to the human-likeness of behavior. Results show that similar to participants' gaze aversion in interaction with a human and android in the previous study, people in this study tended to avert gaze by looking left or right when confronted with the android displaying human-like movement. For all other conditions the salient characteristic is that people show increased gaze aversion by looking down which is similar to the gaze pattern observed in interactions with the mechanical robot Eveliee P1 in the previous study. However, also these conditions differ slightly in the gaze pattern. The authors also report correlation analyses between conditions to compare graph (or gaze pattern) similarities. However, most correlations were misinterpreted as being correlated although not significant. Moreover, the authors rank the importance of behaviors leading to different gaze pattern on the basis of these (partly) insignificant correlations. Although the attempt to estimate the importance of different behaviors with regard to gaze aversion failed, the results of these studies suggest different gaze aversion patterns in interactions with humans, androids and mechanical robots by which human-likeness was characterized by left-right gaze aversion for humans and androids and down gaze aversion for robots. However, a replication of this study by Minato, Shimada, Itakura, Lee, and Ishiguro (2006) reports different results. Although participants showed again more gaze aversion during think- than during know-questions, the directions of gaze aversion differed from the previous studies. Participants interacting with the human interlocutor predominantly averted gaze by looking down. Participants in the android condition averted gaze in diverse directions and “looked around” while thinking, but also looked down. In a second experiment Minato et al. varied whether participants were instructed to lie when answering or to answer truthfully. Gaze aversion in the human condition was longer than in the android condition. Again in both conditions participants looked down when answering questions. However, contrary to the first experiment, participants also frequently looked around while interacting with the human and especially looked more upward. In sum, the analysis of gaze (fixation and gaze aversion) suggests differences of gaze patterns between humans, android robots and mechanical robots. These differences patterns, however, are not consistent across studies although researchers used the same paradigm and the same android robot. Thus, the idea to use gaze aversion as a measure for human-likeness gains some support, but there is more research needed to advance the reliability of this measure.

In a study by Bartneck et al. (Bartneck et al., 2009) participants engaged in short interactions with an android robot. The study addressed two dimensions of the uncanny valley (movement and human-likeness in this case interpreted as anthropomorphism) in a laboratory study using the android robot Geminoid HI-1 (cf. Figure 11). First, they compared an actual human with his android counterpart (Geminoid HI-1 and its originator Prof. Ishiguro) and varied the factor *anthropomorphism* for the android (masked android with a visor, android wearing glasses). Second, the *movement* of the android (or person respectively) was varied. The android or person either showed full movement (head movement, gaze, and randomized subtle movements) or limited movement (looked straight ahead at the participant). For the android conditions prerecorded sentences of Prof. Ishiguro were used as well as his nonverbal behavior which was recorded using motion-capturing. For the android in the limited movement condition all movements except lip-synchronization and eye-blinking were deactivated. Participants engaged in a short interaction with the person or android in which they were asked for their age, university affiliation and name. Results showed that the human was rated as more human-like. However, the human was not rated as more likable, nor were differences found between the android conditions with regard to human-likeness and likability. Movement in the android conditions did not result in any significant effect.

However, Prof. Ishiguro was rated as less human-like in the limited movement condition compared to the full movement condition. The authors discuss the possibility that participants punished the human, because his behavior did not comply with social standards. The android robots, however, may not be subject to these social standards and might therefore be unaffected in their ratings. The authors conclude a) that movement should be considered as multi-dimensional factor, because it carries social meaning which might also vary between humans and robots, and b) that also anthropomorphism is a multi-dimensional concept that includes not only appearance, but also behavior. Again, the exposure time was quite short and the interactions were very restricted, thus, results might be different when participants encounter an android robot for a longer period of time with more freedom regarding the content of the interaction.

The reported laboratory studies with androids differ greatly with regard to the underlying research questions as well as the applied methodology. Noma et al. (2006) used a forced choice task to measure the recognition rates of humans and androids as well as ratings on human-likeness. They found that a moving android was often mistaken as a human when presented in the short time frame of 2 seconds. Similarly, Bartneck et al. (2009) asked their participants to evaluate the human and android in their experiment with regard to human-likeness and likability after a very brief interaction time. Although in this case the human was rated as more human-like, this was not reflected with regard to his likability. In addition, effects for movement are inconsistent. In Noma et al.'s study movement showed a positive effect in terms that the moving android was evaluated as more human-like. However, in the experiment by Bartneck et al. movement did not influence the android's evaluation. In the series of studies comparing androids and humans by measuring participants' gaze (Minato et al., 2004; Minato et al., 2006; Shimada et al., 2006; Shimada & Ishiguro, 2008) movement showed an influence, but across studies the results deliver only a fuzzy picture about the direction of the effects. In sum, these studies show that people react differently to android robots compared to humans, which is in itself not surprising. Results also suggest an influence of movement on participants' evaluation of human-likeness as well as their actual behavior towards robots.

4.3 Testing of explanations for the uncanny valley effect

4.3.1 Perception-oriented explanations

As reviewed in section II.3 possible explanations for the uncanny valley effect are *conflicting perceptual cues, the violation of previously triggered expectations, errors in the prediction of* *movement* or *uncertainty at category boundaries.* At a first glance these approaches of explanation do not seem to be concerned with the same phenomena or processes and stem from diverse research areas. However, they are all loosely tangent to an underlying assumption of mismatching expectations and perceptions in whatever form, causing some kind of additional processing on how to interpret, categorize, or react to this phenomenon. This state of additional processing is often assumed to elicit some kind of uncertainty or cognitive dissonance which is subsequently negatively interpreted and thus the origin of the uncanny valley effect. However, despite this uniform underlying assumption of many investigators on the uncanny valley effect, they refer to different concepts and research areas and thus used a broad range of experimental paradigms. In the following, these concepts will be shortly introduced in order to facilitate understanding, localization and integration of the subsequently presented related work with regard to the uncanny valley effect.

Conflicting perceptual cues can occur within a specific sensory modality (e.g. two visual aspects do not correspond) or between sensory modalities (e.g. discrepancy between visual and proprioceptive input). Welch and Warren (1980) review that intersensory discrepancies are often measured by either adaptation to that discrepancy or by the so-called intersensory bias which describes the effect that one modality biases the other (or both bias each other, e.g. visual power over proprioceptive information about spatial location; this effect has also been shown for virtual environments, cf. Burns et al., 2006). Welch and Warren name as variables that affect the magnitude of intersensory bias -among others- for instance structural factors such as the amount of discrepancy or cognitive factors such as the subjects' awareness of the intersensory discrepancy. Epstein (1975) reviews experiments which deal with within-sensory cue discrepancy which is also often resolved also by adaptation, a recalibration process for re-evaluation of sensory information (see also Wallach, Bacon, & Schulman, 1978). From the opposite perspective, Stein and Stanford (2008) review work on multisensory integration and summarize that merging information from multiple senses can enhance the physiological salience of an event, increase the ability to render a judgment about its identity, and initiate responses faster than would otherwise be possible. However, all this work used experimental paradigms from the field of psychophysics (e.g. varying location of visual and auditory stimuli, or visual and proprioceptive information). Although the impact of multisensory integration with regard to these paradigms has been demonstrated for different brain regions (in humans as well as in monkeys) using diverse techniques (single-neuron, event-related-potential recordings, brain-imaging techniques) little is known about the impact of multisensory integration with regard to higher-order multisensory phenomena, such as speech perception and multisensory semantic congruency. Although the authors propose that "multisensory integration is crucial for high-level cognitive functions in which considerations such as semantic congruence might determine its neural products and the perceptions and behaviours that depend on them" (Stein & Stanford, 2008, "Summary", para. 5), they also acknowledge that the coding dimensions for these higher-order functions are undoubtedly much more complex and yet has to be researched more deeply. According to Roach, Heron, and McGraw (2006) multisensory integration can be understood as a process involving maximum-likelihood estimations which consider the contribution of each system to the ultimate multisensory percept depending on the relative reliability of the information it provides. These estimations are based on prior knowledge about the correspondence between cross-modal inputs. These thoughts go hand in hand with the assumptions of *predictive coding* (e.g., Kilner, Friston, & Frith, 2007; Rao & Ballard, 1999) where additional processing is needed to process biological or non-biological motion when the observed movement deviates from predicted motion behavior. With regard to the uncanny valley effect it has been proposed that all these mechanisms to deal with discrepancies or deviations from expected or predicted input cause cognitive dissonance (Burleigh et al., 2013; Chaminade et al., 2010; Saygin et al., 2012; for cognitive dissonance cf. Festinger, Irle, & Möntmann, 1978). Since states of cognitive dissonance are commonly interpreted negatively, this is assumed to be the cause for these negative uncanny valley related reactions. When regarding robots it is obvious that very human-like androids in particular provide conflicting perceptual cues both within and between modalities, e.g. considering their human form, but unrealistic skin texture or their human-like appearance and often machinelike behavior. Moreover, we build upon our prediction of both biological and non-biological movement on prior knowledge/experiences, but experiences of robotic movement are scarce for most people. Moreover, robots are often designed to imitate biological movement which contradicts our predictive scheme that biological movement is performed by living beings only.

Also ***uncertainty at category boundaries*** has been put into the context of Festinger's cognitive dissonance theory. It is widely acknowledged that humans use categorization to make sense of what happens around them. Categorization as a principle has been investigated on different levels with different methods under different labels. Medin and Barsalou (1990) compare, for instance, theories and methods used by researchers interested in sensory perception categories who mainly investigate psychophysical issues concerning how physical energy relates to perceptual experience (e.g., sound, color) with those used by researchers interested in generic knowledge categories who concentrate on topics like semantic analysis, memory organization, knowledge representation and abstract thought. For both categorization processes empirical evidence has been generated. But although both intuitively seem to have some things in commons they are distinct research areas. Both will be described separately with respect to their meaning for the uncanny valley while discussing their similarities.

Harnard (1990) defined *sensory perception categories* or the phenomenon of *categorical perception* as "a qualitative difference in how similar things look or sound depending on whether or not they are in the same category" (Harnad, 1990, p. 2). The specific experimental paradigm compares discrimination (telling things apart) or identification performance (labeling things) for a set of stimuli. The underlying principle is the assumption that although physical differences between stimuli are of equal size, they are perceived to be larger or smaller depending on whether the stimuli are in the same category or different ones. Harnard exemplifies this with colors, stating that two shades of green might look more alike than a shade of green and a shade of yellow, although the difference in wave length might be the same. Thus, two conditions have to be met in order for categorical perception to occur. First, stimuli ranging along a (in the case of psychophysics: physical) continuum are given one label on one side of a category boundary and another label on the other side. Second, the subject can discriminate smaller (physical) differences between pairs of stimuli that straddle that boundary than between pairs that are within one category or the other. Or as Harnad puts it, categorical perception "is a quantitative discontinuity in discrimination at the category boundaries of a physical continuum, as measured by a peak in discriminative acuity at the transition region for the identification of members of adjacent categories" (c.f. Harnad, 1990, p. 3).

Medin and Barsalou (1990) address categorization in terms of generic knowledge categories (cf. also frames (framing theory; e.g. Minsky, 1975) or schemata (schema theory, e.g. Bartlett, 1932)) and distinguish between *all-or-none categories* and *fuzzy categories*. With regard to the first type of categories they can be either *defined* or *well-defined*. In well-defined categories all members share a common set of features and a corresponding rule defines these as necessary and sufficient conditions for membership (e.g. an individual with the features adult, unmarried, male, human is a "bachelor"). In defined categories the rule can be disjunctive in that the members of a category can fulfill any one of a set of features with every single features being a sufficient condition for category membership (e.g. different ways for getting a strike in baseball). However, fuzzy categories do not have a rule that defines all of its members and excludes non-members. Membership is more a matter of degree, or of similarity. A member of a specific category has more similarities with other members of that category than with non-members. In contrast to experiments on categorical perception on a sensory perception level, experimental paradigms on the level of higher order categories (generic knowledge) often measure how quickly and easily an instance is judged to be a member of a category. Moreover, participants are frequently asked to judge the member's typicality as a member of that category. And lastly, what subjects report has been examined in regard to they are accomplishing the categorization (i.e., what features or rules they feel they use; cf. Harnad, 1990, p. 18). Harnad exemplifies that the reaction time for identifying a robin as a bird might be shorter than for identifying a penguin as a bird. Moreover, the robin would be rated as a more typical example for the category bird. When asked about their evaluation criteria, subjects would report that a robin has more of the features characteristic of a bird than a penguin does. Medin and Barsalou discuss the different ways for classification: by rules (as explained above for), or with regard to the fuzzy categories by prototype and by exemplar. A prototype of a category "contains the characteristic attributes of its category's exemplars, namely, attributes that are highly probable across category members, but that are neither necessary or sufficient for category membership" (Medin & Barsalou, 1990, p. 463). Thus, category members, such as robins and penguins in the bird category, can resemble the prototype to a greater or lesser degree and this subsequently would result in different reaction times and typicality judgments. More typical members who show more similarities with the prototype of a category will be easier classified as members than those which show fewer similarities with the prototype. When people perform classification by exemplars, they classify "entities on the basis of their similarity to memories of previously experienced category members" (Medin & Barsalou, 1990, p. 464).

Medin and Barsalou state that it is not clear whether people exhibit categorical perception when processing generic knowledge categories. On the one hand the authors emphasize that most generic knowledge categories include at least some perceptual features and that the classification of generic knowledge categories such as cars, people or houses "often appears to depend heavily on perceptual properties" (Medin & Barsalou, 1990, p. 456). On the other hand, generic knowledge categories also rely on more abstract concepts (can get sick, living) and these are often dependent on background theories and beliefs about the world. In contrast, Harnad (1990) considers sensory perception categories and general knowledge categories in a hierarchical framework with higher-order concrete and abstract categories built out of elementary psychophysical categories. Moreover, he concludes that the nature of the representations of both categories (e.g. whether they consist of defining features or prototypes) and how categorization is accomplished (e.g., whether by detecting defining features or degree similarity to a prototype) will depend on whether the categories in question are all or none or fuzzy.

As Mori’s quotation in section I already suggested it is not easy to give a definition for what a robot actually is. Considering Medin and Barsalou’s elaborations on categories, robots might be best understood as a fuzzy category which does not have a rule that defines all of its members and excludes all non-members. The *category robot* might be best captured or defined by referring to a prototype or an exemplar. However, exemplars of this category differ extremely (e.g. unmanned aerial vehicles versus humanoid robot), and especially because of the limited access to actual robots the category could also be defined by those exemplars we frequently see in the media biasing the category. Moreover, with regard to categorical perception it is very hard to gradually change physical properties of actual robots. This is why investigators examining the uncanny valley under the assumption of an effect of categorical perception frequently use virtual faces (see below) in their studies.

In conclusion, it seems that one phenomenon traverses different levels of perception and cognition. Depending on the level or information processing, the research area, or the methods used to examine the phenomenon it is called conflicting perceptual cues, intersensory discrepancy, or predictive coding. Stein and Stanford (2008) assume that multisensory integration also occurs on a higher semantic level and Harnad (1990) stated a similar assumption for sensory categorical perception which might constitute categorization processes on the level of generic knowledge categories. Furthermore, in all these diverse research areas processes were mentioned which deal with mismatched information and are held responsible for the uncanny valley effect.

In the following uncanny valley related research with regard to the previously mentioned levels of perception and cognition will be presented.

Mismatches between movement and appearance

There is ample empirical work on the effects of a mismatch between movement and appearance. In this regard, a number of studies focus on differences in motor resonance during the observation of human (biological) and robotic (not biological) movement. This work builds upon neurophysiological evidence that certain brain regions involved in executing actions are also activated when people just observe that same action which is also known as the mirror (neuron) system (MNS) or action observation network (AON; Gallese, Fadiga, Fogassi, & Rizzolatti, 1996; Rizzolatti, Fadiga, Gallese, & Fogassi, 1996; Rizzolatti, Fogassi, & Gallese, 2001). The underlying hypothesis is that observing and executing actions have shared representations in that they at least partly involve the same cognitive processes. Thus, observing an action leads to brain activations which mirror those for executing that action. Neural activations which are associated with the AON have been located in ventral and dorsal premotor cortices, primary motor cortex, and inferior parietal lobule (cf. e.g. Buccino et al., 2001; Buccino et al., 2004; Rizzolatti et al., 1996). Moreover, behavioral studies have shown that motor resonance for a perceived action facilitates simultaneously execution of the same action, but inhibits the execution of different actions from the observed one causing an interference effect (Brass, Bekkering, Wohlschläger, & Prinz, 2000; Edwards, Humphreys, & Castiello, 2003). However, studies with handicapped persons suggest that the mirror neuron system is only activated when the agent is capable of performing this movement. Aziz-Zadeh, Sheng, Liew, and Damasio (2012) summarize after experiments with a congenital amputee that “the action goal (e.g., reach-to-grasp, bite) must fall within the repertoire of the observer, regardless of how the goal is accomplished” (Aziz-Zadeh et al., 2012, p. 812) to elicit motor resonance. Moreover, studies with expert ballet dancers showed that female and male expert dancers show greater brain activity when observing actions which are in their own gender-specific motor repertoire (Calvo-Merino, Grèzes, Glaser, Passingham, & Haggard, 2006). Thus, motor resonance will not be elicited when persons observe movements they themselves cannot perform and motor resonance will be elicited less when observing movement which is usually not executed although possible and frequently observed. In addition, there is a debate about whether people differentiate between biological (human) and non-biological (robotic) movement and whether this effect -if present- exists because it evolved as the basis for social functions (theory of mind, action understanding) or because human actions have been observed more frequently than non-biological movements and thus our perception is better trained for human biological movement (c.f. also Press, 2011 for a review).

A number of studies compared arm movements of human arms and (industrial) robotic arms to study differences in the perception of biological and non-biological movement. Tai, Scherfler, Brooks, Sawamoto, and Castiello (2004) showed in a positron emission tomography study (PET) activation in the left ventral premotor area during action observation (grasping for an object) of a human arm, but not during action observation of a robotic arm. In this study participants saw the agents performing the same grasping action several times. In contrast, an fMRI study by Gazzola, Rizzolatti, Wicker, and Keysers (2007) indicated that motor resonance is elicited by both human and robotic movement. However, by showing the participants different actions repeatedly, Gazzola et al. found an effect for repetitive vs. non-repetitive movement. They compared the analysis of participants' brain responses only during the first observation of an action with the neural activity during observation of all trials of an action. In contrast to repetitive human movement repetitive robotic movement is obviously perceived as not driven by an intention or goal and subsequently elicits less activation in the mirror system. Oberman, Cleery, Ramachandran, and Pineda (2007) found in an electroencephalography (EEG) experiment that motor resonance is observable for both human arm movement and robotic arm movement even when the action is not explicitly goal driven (e.g. just open and close hand instead of grasping an object). The above mentioned motor resonance interference effect was also used to study differences in the perception of human and robotic motion. In an experimental face-to-face study by Kilner, Paulignan, and Blakemore (2003) participants were asked to make arm movements while observing either an industrial robot arm or another human making the same or qualitatively different arm movements and the variance in their performed arm movement was taken as a measure of interference. As expected, participants observing a human doing incongruent arm movements showed more variance in their arm movements. No significant effect was found when participants observed a robotic arm performing incongruent arm movements. The authors summarize that the observed differences in the interference effect prove that interference is not due to increased attentional demands or task complexity, but that this differences supports the assumption that the brain processes biological and non-biological movements differently. Moreover, the authors point out that "There are many aspects of human movement that could cause interference in the incongruent condition, including the "biological" velocity profile of the movement, the bodily posture, or the presence of bodily, head, or facial features of the human. Which aspect of the human movement is the trigger for the interference, and which is absent in robotic movements, is unknown and requires further experimentation." (Kilner et al., 2003, p. 524). Addressing the aspect of appearance, Oztop, Franklin, and Chaminade (2004; see also Oztop, Franklin, Chaminade, & Cheng, 2005) adapted the paradigm from Kilner et al., but confronted participants with a human and a humanoid robot, instead of an industrial robot arm. They found significant interference effects due to movement incongruence for both interactions: with the human and the humanoid robot, although the ratio between incongruent and congruent conditions was slightly higher when subjects interacted with a human compared to a robot. Subsequently, Chaminade, Franklin, Oztop, and Cheng (2005) addressed the aspect of motion characteristics. While in Oztop et al. human and robot performed movements with comparable kinematics thanks to motion capturing, in the follow-up study participants interacted only with the humanoid robot showing either biological motion (realistic model of human motion) or artificial motion (decreased degrees of freedom). They found a significant interference effect only when the robot's movements followed biological motion. The authors assume that motion is a significant factor for the interference effect and that the observed differences in interference in Kilner et al.'s study are indeed due to the robotic movement of the robot arm. This assumption is also supported by studies showing that the action observation network is also activated when observing point-light displays in biological motion in contrast to non-biological motion or distorted biological motion (Bonda, Petrides, Ostry, & Evans, 1996; Beauchamp, Lee, Haxby, & Martin, 2003; Grèzes et al., 2001; Saygin, 2004). However, there is also evidence for the influence of form on activation in the AON. In comparison to human stimuli there was less activation for kinematic similar moving square shaped objects (Brass, Bekkering, & Prinz, 2001), balls (Oberman et al., 2005), computer generated points (Biermann-Ruben et al., 2008; Gowen, Stanley, & Miall, 2008; Kessler et al., 2006) and even virtual reality hands (Perani et al., 2001) and robotic hands with exactly the same kinematics (Press, Bird, Flach, & Heyes, 2005). However, a study by Kupferberg et al. (2012) comparing motor interference effects of a human, a humanoid robot, and an industrial robot arm with either artificial (industrial) or human-like joint configurations found motor interference effects for all actors given a human-like joint configuration, but no motor interference given a non-human joint configuration. The authors conclude that a human-like joint configuration is more important than other human-like features like appearance. Press summarizes that "there have been a number of studies indicating greater AON activation when observing human stimuli, relative to non-human stimuli. There are observable influences both of the form and the kinematics of the stimuli." (Press, 2011, p. 1414).

Saygin, Chaminade, Ishiguro, Driver, and Frith (2012) criticize that the previously reported studies did not sufficiently explore nor separate the influence of biological appearance and biological motion and thus examine the influence of an agent's biological appearance, an agent's biological movement and the combination of both. During their fMRI study (Saygin et al., 2012; also reported in Saygin, Chaminade, & Ishiguro, 2010) participants saw videos of an android robot (Repliee Q2), the human after whom the android was modeled and a "mechanic version" of the android, namely the android without the covering silicon skin. Results show similar patterns of brain activation in the lateral temporal cortex for the robot (non-biological appearance and motion) and human (biological appearance and motion) condition, but a widespread pattern including also parietal and frontal cortex for the android (non-biological motion, but biological appearance). The authors suggest that their results fit into the predictive coding framework (e.g. Kilner et al., 2007; Rao & Ballard, 1999) according to which brain activity “will be higher for a stimulus which is not well-predicted or explained by a generative neural model of the external causes for sensory states (Friston, 2010).” (Saygin et al., 2012, p. 419). In a similar setting, but using near-infrared spectroscopy Shimada (2010) examined how appearance or kinematics influence motor area activity during action observation. Participants saw videos of a computer-generated human and a computer-generated robot e.g. grasping for an object. Like Saygin et al., Shimada found an interaction effect for appearance and kinematics resulting in strong deactivations in sensorimotor areas when the subject saw a human agent performing robotic actions in contrast to the human agent performing human-like movement and the robot performing robotic movement.

While these studies solely focused on motor resonance, there is some empirical work on motor resonance in combination with the perception and encoding of emotion. Chaminade et al. (2010) report brain responses in the ventral premotor and inferior frontal gyrus, amygdala and insula to emotional expressions by a human and a robot. Results indicate additional visual processing during the perception of the robot in occipital and posterior temporal cortices. Regions involved in processing of emotions (left anterior insula for the perception of disgust, orbitofrontal cortex for the perception of anger), however, showed reduced neural activity when observing the robot compared to observing a human. In a very similar experiment Gobbini et al. (2011) found similar premotor activation for human and robotic face expressions. Moreover, both evoked activity in face-responsive regions. Also Dubal, Foucher, Jouvent, and Nadel (2011) examined whether human and robotic faces are perceived similarly using EEG. They found that emotional displays shortened reaction times for discrimination of neutral and happy faces. Moreover, EEG results suggest that robotic emotional displays are encoded as early as human emotional displays. However, robots elicited a later and lower N170 component which corresponds to visual areas selective for face recognition and suggest additional processing due to fewer facial features in robotic faces.

Finally, also different types of robots can lead to different brain activation patterns with regard to motor resonance and emotion perception. Miura et al. (2008) investigated neural activation in the mirror neuron system during the perception of a bi-pedal robot, a robot moving on wheels and a human while performing neutral movements or movements assumed to be emotionally positive (walking happily). Results show that in all conditions there was a general activation in the bilateral occipito-temporal junction, right ventral premotor area, and inferior frontal gyrus, as well as in the region within the superior temporal sulcus which is associated with social perception (Lieberman, 2007; Lotze et al., 2006). However, there were differences when comparing the neutral or emotional walking for the bi-pedal or wheel robot. When contrasting the bi-pedal robot's neutral and emotionally positive walking this results in higher activation for the emotional walking in the left orbitofrontal cortex (which is involved in, for example, emotion processing, empathetic processing of emotional facial expression, painful stimuli for others, interpretation of expressive gestures) than the contrast of the wheel robot in both conditions. The latter contrast showed higher activation in the occipito-temporal junction which was interpreted as additional processing in the interpretation of body (emotional) movements. However, the authors do not report contrasts between the human conditions and the robot conditions.

Summary. In conclusion, results are inconsistent. Motor resonance is elicited both by humans and robots. Differences in neural activation might occur when the behavior is or is not perceived as intentional (Gazzola et al., 2007). Moreover, different studies showed that humans, as well as different types of robots (robot arm, android, mechanical robot, robot face, bi-pedal robot, wheel robot) performing actions or emotional behavior (simple arm/hand movement, gesturing, facial expression or "walking happily"), in general activate brain areas involved in action observation (Chaminade et al., 2005; Chaminade et al., 2010; Gazzola et al., 2007; Gobbini et al., 2011; Kilner et al., 2003; Kupferberg et al., 2012; Miura et al., 2008; Oberman et al., 2007; Oztop et al., 2004; Saygin et al., 2012; Shimada, 2010; Tai et al., 2004; Wykowska, Chellali, Al-Amin, & Müller, 2012), face-recognition (Dubal et al., 2011; Chaminade et al., 2010; Gobbini et al., 2011) and emotional processing (Chaminade et al., 2010; Dubal et al., 2011; Gobbini et al., 2011; Miura et al., 2008), but there are indicators that the amount of activation might vary when comparing different types of robots or robots and humans (e.g. Kupferberg et al., 2012; Miura et al., 2008; Saygin et al., 2012; Shimada, 2010). Aziz-Zadeh, Sheng, Liew, and Damasio (2012) also conclude that, considering the studies of Gazzola et al. and Tai et al., the observation of human actions activated motor-related areas bilaterally, whereas observation of actions made by robots or non-conspecifics activated only the left motor-related areas. Press (2011) concludes that there is more evidence that the biological tuning of the AON resulted from greater opportunity to associate the observation of human movement with the execution of corresponding actions and less evidence for the assumption that this biological tuning evolved through natural selection to support higher sociocognitive functioning. This leads to the assumption that differences in motor-resonance and subsequently the negatively interpreted prediction error which can occur in action observation for robots (c.f. Chaminade et al., 2010) might be overcome by training.

Mismatches between different aspects of appearance

Besides empirical work on prediction errors caused by a mismatch of movement and appearance, also mismatches of different aspects of solely appearance (like surface structure, proportion of faces and facial features, etc.) have been mentioned as possible causes of negative emotional reactions.

Based on the early studies which used morphing techniques to emulate the uncanny valley effect, also Seyama and Nagayama (2007) present a series of studies in which participants rated morphed pictures with regard to their pleasantness. The degree of realism of faces was varied by morphing between artificial (dolls and masks) and real human faces. In their first experiment none of the morphing sequences resulted in negative peaks for pleasantness ratings. The authors argued that this might be due to the fact that the artificial faces were already very realistic. Subsequently, in the second experiment the images were morphed asynchronously with regard to the eyes and head, by morphing only the eyes of a doll into those of the human while the head was unchanged and then adjust head size in the last morphs, or by morphing the artificial doll head into the human head while the eyes were unchanged and then adjust eye size in the last morphs, respectively. In contrast to the first experiment, pleasantness ratings were influenced by realism percentages (in the morphing sequence) and the lowest scores were significantly lower than those for the unmorphed images of the dolls or the humans leading to the authors' argument that the non-occurrence of the uncanny valley in the first experiment cannot be attributed to a limited range of realism. Conversely, the authors suggest "that mismatched realism may be a necessary condition for the uncanny valley's emergence." (Seyama & Nagayama, 2007, p. 343). Seyama and Nagayama did additional testing on abnormal eye size in a third experiment. Here they first manipulated the eye size of artificial faces and then morphed the image with a real human face. They found that abnormal eye size did not result in unpleasantness for artificial faces. However, images with abnormal eye size and higher percentages of realism (while morphing to the real human face) resulted in unpleasantness with the lowest pleasantness rating for a real human with 150% eyes. Seyama and Nagayama discuss that participants might be accustomed to artificial faces with abnormal facial features (e.g. in Japanese Manga comics characters often have abnormal eye sizes), however, for human faces they might rely on "data of the statistical distribution of the size of real human eyes from past experience" (Seyama & Nagayama, 2007, p. 348) causing unpleasantness when this criterion is not met.

Seyama and Nagayama (2009) examined whether natural and artificial faces are processed using different mechanisms in the human visual system or using common mechanisms, but different evaluation criteria or sensitivities to these faces. They applied a variant of the face distortion aftereffect (Webster & Maclin, 1999) which is the phenomenon that test faces appear to be distorted in a manner opposite to a previously presented adaptation face's distortion. Thus, in this case they assumed that the observation of an adaptation face with abnormal huge eyes would lead to underestimation of the eye size of test faces. They found that both natural and artificial adaptation faces induced this bias for both real and artificial faces. However, differences in the adaptation time period suggest that the "uncanny valley may reflect that artificial faces are processed inefficiently by perceptual mechanisms that are common for processing natural and artificial faces." (Seyama & Nagayama, 2009, p. 321).

Green, MacDorman, Ho, and Vasudevan (2008) also investigated the influence of face proportions in participants' perceptions of these faces. Based on pictures of real people, androids, mechanical-looking robots, and two- and three-dimensional characters they produced videos in which one facial proportion was warped in both directions: more and less cheek width, eye separation, face height, and jaw width. Participants were presented with a randomly selected video frame as starting point in a Flash application and could browse through the video in order to find the "best face" within the warping sequence. Moreover, they were requested to indicate the last acceptable face within a warping sequence for both warping directions and they should rate the original pictures with regard to how female, creepy, sexy, ugly, alive, human-like the pictures are. Results show that participants were increasingly sensitive to the best face (for all four proportion dimensions) as ratings for the attributes human-like and attractive increased. They also showed decreased tolerance for distorted facial features as ratings of attractiveness increased. The authors conclude that because there is no correlation between the acceptable ranges for facial proportions and ratings of human-likeness an "uncanny valley was found when participants were most ambivalent about the human-likeness of a face." (Green et al., 2008, p. 2474).

In order to examine the effect of mismatched perceptual cues with regard to facial features MacDorman, Green, Ho, and Koch (2009) conducted four subsequent studies on the influence of a computer generated human character's facial proportions, skin texture, and level of detail on perceived eeriness, human-likeness, and attractiveness. In the first study participants rated a 3D model of a male human head presented at three different textures (photorealistic model, bronze model, line texture model) and eleven levels of detail (polygon count, lines in line texture) with regard to their eeriness and human-likeness. Results showed increased human-likeness ratings for increased level of detail, but only for the bronze and photorealistic textures and in general more photorealistic textures were perceived as more human-like. In contrast to the uncanny valley hypothesis, in this study the ratings of eeriness were lowest for the photorealistic texture, decreased as the level of detail increased for the bronze and photorealistic textures and decreased as the human-likeness ratings increased. The authors discuss the influence of evolutionary and artistic design for the unexpected non-occurrence of the uncanny valley effect. Their 3D model of a human was a resemblance of a human face and the humanoid robots or bunraku puppets which are discussed in Mori's uncanny valley were products of artistic design. However, according to MacDorman et al. changing the polygon count or texture in the 3D models would not involve any artistic design process in creating new images. Given that the authors attempted to investigate the influence of perceptual mismatches as the origin of the uncanny valley effect this argument is inconclusive. In the second experiment, participants followed the same procedure as in Green et al. (2008) and adjusted the faces of the first study along a facial dimension (either eye separation or face height) to determine and select which proportions looked best using a Flash application. As a result participants' accuracy in identifying the ideal facial proportions increased with texture (best in photorealism), but was not influenced by the level of detail. In the third study MacDorman et al. wanted to test whether extreme facial proportions are perceived as eerier at higher levels of detail which they suggest support the evolutionary explanation that humans are highly sensitive to defects in human-looking faces because of pathogen avoidance and mate selection reasons. Again using the Flash application participants had to choose the level of detail at which the faces looked eeriest to them. Atypical facial proportions were shown to be more disturbing on photorealistic faces than on other faces and were more disturbing on higher levels of detail. In the fourth study, following the experimental paradigm of Seyama and Nagayama (2007), Mac Dorman et al. asked participants to rate virtual faces with mismatched skin and eye properties with regard to their eeriness, naturalness, and attractiveness. They expected that a mismatch in the level of eye and skin photorealism would increase eeriness and that following the results of Seyama and Nagayama eye enlargement would influence eeriness ratings of more photorealistic faces by a greater extent than less photorealistic faces. Thus faces varied in their level of skin photorealism (from natural to bronze) and eye photorealism resulting in 25 different faces.

Additionally, a second set of these 25 faces were presented with 50% enlarged eyes. Results showed that for the first set of pictures, those pictures with matching levels of photorealism were rated more positively and those with mismatching features were rated as more eerie. The authors see this as support for the synergy effect in the extended uncanny valley model (e.g., MacDorman et al., 2005; Ishiguro, 2006). For the second set of pictures, the results of Seyama and Nagayama could be reproduced. Extreme facial features like enlarged eyes increased eeriness ratings and decreased perceived naturalness and attractiveness. Surprisingly, reduced photorealism was sometimes rated better than the most photorealistic pictures. “This shows that backing away from photorealism can sometimes make a CG character less eerie and more attractive.” (MacDorman et al., 2009, p. 708). Accordingly, the authors introduced design guidelines for the creation of computer-generated faces in order to avoid uncanny reactions.

Also on the basis of computer-generated faces Burleigh, Schoenherr and Lacroix (2013) tested two hypotheses, namely the atypical feature and the category conflict hypothesis. Burleigh et al. assumed that previous work using morphed pictures (e.g. MacDorman and Ishiguro, 2006) probably found uncanny responses because images contained atypical features generated during the morphing process when one image inherited features of a neighboring image. For instance, in MacDorman and Ishiguro’s (2006) study the most eerie images had a black dot in the forehead which is unusual and also not plausible. However, Burleigh et al. state that with regard to the atypical feature hypothesis “Plausibility is an important condition of our hypothesis which is satisfied if and only if the feature belongs to the same ontological category as the stimulus. […] Thus, features that are unusual and also plausible should be expected to elicit negative affect as a function of human-likeness.” (Burleigh et al., 2013, p. 760). This can be explained by the example of Seyama and Nagayama’s (2007) real and artificial faces with enlarged eyes. For the real faces this atypical feature was unusual but still plausible, because one might encounter a person with very huge eyes. When, however, the images are more artificial atypical features are plausible but less unusual resulting in less negative responses. This was also discussed by Seyama and Nagayama (2007) who stated that enlarged eyes are quite normal for Japanese Manga characters. Following a similar procedure as MacDorman et al. for stimulus creation in their fourth study, Burleigh et al. (2013) also generated computer-generated faces which varied with regard to the polygon count (geometric realism of face) and proportions eye size, mouth height, mouth size, face height, and eye separation (prototypicality of face). Faces were rated with regard to their human-likeness, eeriness, fear, disgust, and attractiveness. As in previous work (Hanson et al., 2005; Hanson, 2006; Lay, 2006; MacDorman & Ishiguro, 2006), eeriness and human-likeness ratings were plotted for all stimuli separately and the authors tested whether linear or non-linear (quadratic or cubic) models fitted best to the data and found that in contrast to Mori's hypothesis linear models fitted best for all four stimuli. Similar bivariate linear functions were found when plotting eeriness ratings along the two manipulated variables - geometric realism and prototypicality resulting in planar surface plots. In a follow-up study Burleigh et al. examined whether the uncanny valley effect is due to category conflict or due to atypical features on otherwise typical human-like stimuli. They thus again created artificial faces on two continua of human-likeness. The first series of faces merges the category human with the category non-human animal. The "animal" in this case was a mixture of a human head with goat-like appearance which was considered to have enough detail of a non-human category. In the second continuum Burleigh et al used the same mechanism as MacDorman et al. (2009) in one of their experiments and merged the artificial faces from a human-like color to a bronze model of an artificial face (Figure 12). For both continua feature atypicality was also varied in that one eye in the artificial face was enlarged.

Figure 12: Examples for stimuli used in Burleigh et al. 2013 (left: animal-human category morphs; right: texture morphs with atypical feature of one enlarged eye)

Again, eeriness and human-likeness ratings as well as pleasantness and human-likeness ratings were plotted for all stimuli separately and the authors tested whether linear or non-linear (quadratic or cubic) models fitted best to the data. While for the continuum with different skin coloration they observed again a linear relationship, data for the continuum addressing category membership could not be explained by a linear function although a linear trend was observable in the plot. There were outliers in the middle between the two extremes which support the author's hypothesis that conflict of categories elicits a negative response leading to Mori's assumed non-linear curve. Moreover, human-likeness ratings and eeriness ratings were plotted against both continua in combination with feature atypicality resulting in four surface plots which resulted again in planar surfaces. The author's prediction that an atypical feature would elicit more eeriness at higher levels of human-likeness than at lower levels did not hold true. However, greater feature atypicality, combined with less human-likeness, resulted in higher eeriness ratings. The authors conclude that their results as well as previously obtained results showing an uncanny valley effect “might be accounted for on the basis of the stimulus belonging simultaneously to multiple ontological categories, which elicits a state of discomfort because it is ambiguous and conflicting” (Burleigh et al., 2013, p. 770), because also in those studies different categories were merged (e.g. robots and humans in MacDorman & Ishiguro, 2006; Mitchell et al., 2011; Saygin et al., 2012; or dolls and humans in Seyama & Nagayama, 2007). However, this does not explain the failures to produce an uncanny valley effect although merging different categories (e.g. Hanson et al., 2005; Hanson, 2006).

Cheetham, Suter, and Jäncke (2011) also addressed category conflicts as a possible explanation for uncanny effects using morphed pictures of human and avatar faces. In order to determine the presence and location of the human-avatar category boundary Cheetham et al. asked participants in the first study to complete a forced choice classification task and looked for those morphs with the highest decision uncertainty. Results showed that participants identified those images correctly as human or avatar which were at the extremes of the continuum with decreasing correctness when coming to the middle of the continuum. The authors identified the category boundary to be at the morphs in the mid-point of the continuum where also reaction times were longest. In a subsequent study participants engaged in a perceptual discrimination task. Participants were presented pairs of faces which could be either the exact same (human or avatar) images, both human (but different) images, both avatar (but different) images or mixed pairs. Moreover, mixed pair images could be either from the extreme ends of the continuum or more from the middle of the continuum. Participants performed same-different judgments. Between-categories face pairs (mixed pairs) were identified as different more often than within-categories pairs (both human or both avatar). Moreover, the within-categories face pairs were more often rated as being different than pairs with the exact same image (e.g. two identical human images). Cheetham et al. see this as evidence for an existing category boundary. In a subsequent fMRI study applying a pair repetition priming paradigm the authors investigate differences in the processing of human and non-human (i.e. avatar) stimuli. As in the previous study pairs of images were presented as either being the exact same image, or belonging to the same category (both human or both avatar) or belonging to different categories (one human, one avatar). Physical change within a category caused activation in bilateral mid-fusiform areas and a different right mid-fusiform area. When, however, there was a category change within the presented face pairs then activation depended on the direction for category change. Regions sensitive to the human-to-avatar category change included caudate head, putamen, thalamus, red nucleus. Regions sensitive to the avatar-to-human category change included hippocampus, amygdala, mid-insula. Cheetham et al. discuss that Mori's theory did not consider that there might be variation in human-like appearance also within the human category not only when regarding human-like, but non-human objects. Although the images used in this study were morphed and thus artificial, some of these technically artificial morphs were explicitly judged to be human. This tackles a methodological uncanny valley critique: in a lot of studies "the human image is treated as a general point of reference irrespective the fact, as shown in the present study, that there are differences in human-likeness within the human category" (p. 9). Moreover, Cheetham et al. suggest reframing Mori's theory in terms of category processing, since their results suggest a category boundary between the avatar and human faces as indicated by increasing reaction times and increased decision uncertainty for those morphs close to the boundary and increased discrimination accuracy for face pairs when faces are drawn from either category instead of from the same category. Moreover, the imaging data suggest that different brain regions are responsible for processing change in category and change in physical similarity.

The results from the forced choice classification task could be reproduced by Cheetham, Pavlovic, Jordan, Suter, and Jancke Cheetham et al., 2013 again revealing a sigmoid shape for accuracy (highest accuracy of discrimination at the extremes of the continua, lowest accuracy in the middle) and the longest response latency corresponded with the position of the identified category boundary. In this follow-up study the authors also examined participants visual attention directed to the stimuli by using eye-tracking data. Based on the assumption that longer duration of fixations indicates greater task difficulty and greater processing demands when discriminating between similar stimuli, they expected higher durations of fixation near the category boundary. Moreover, number of fixation and duration of fixation (dwell) was examined separately for different facial features -namely eyes, nose and mouth- in order to investigate whether the relative importance of these facial features changes as a function of the difficulty of perceptual decision making at different points along the human-likeness dimension. Finally, the authors expected gender differences in that women would show shorter response latencies than men and more and longer fixations related to the eyes. Contrary to their expectations, the number of fixations to the eyes, nose, and mouth did not differ between faces at the category boundary and faces at the extremes of the avatar or human category. When however comparing the three facial features with each other participants spent considerably more attention to the eyes as can be expected according to the face feature hierarchy (e.g., Althoff & Cohen, 1999; Walker-Smith, Gale, & Findlay, 1977). When regarding dwell time there was an effect observable for categorization ambiguity. Ranging from the avatar extreme in the continuum to the middle of the continuum where ambiguity increases there was a relative shift of dwell time away from the nose region to the regions of the eyes and mouth. As expected women showed shorter response latencies and when regarding the facial features the eyes were more salient relative to the nose for women than for men which is consistent with previous findings that women are faster in face processing and pay more attention to eyes (Hall, Hutton, & Morgan, 2010).

Also Yamada, Kawabe, and Ihaya (2013) hypothesized that uncanny responses might be related to a difficulty in object categorization and used morphed continua to investigate this assumption. Morphs included real human faces and the cartoon face of Charlie brown, as well as a stuffed Charlie Brown toy in the first experiment. The results revealed a category boundary at which participants showed the longest latency, the highest ambiguity in categorization, and reported the lowest likability score. These results could be reproduced also with morphing continua of real and cartoon/stuffed dogs (Snoopy). Overall the morphs of real humans with cartoons and stuffed toys looked very unrealistic except the real human face. Moreover, it is unclear why the authors also used these popular and stylized cartoons of Charlie Brown and Snoopy. Finally, the authors report that when morphing human faces and letting participants categorize them as male or female the effect of categorization difficulty on evaluation was weak. However, the results are quite in line with the general picture that category uncertainty results in higher response latency, lower category accuracy and sometimes negative evaluations of objects at category boundaries.

Summary. Altogether, a number of studies used morphing techniques to examine the uncanny valley effect by gradually changing properties of the faces under examination (Burleigh et al., 2013; Cheetham et al., 2011; Cheetham et al., 2013; Green et al., 2008; MacDorman et al., 2009; Seyama & Nagayama, 2007; Seyama & Nagayama, 2009; Yamada et al., 2013). With regard to conflicting perceptual cues, results show uncanny valley effects for morph sequences in which distinct features are morphed asynchronously resulting in facial proportions deviating from the norm (Seyama & Nagayama, 2007). However, sensitivity for deviating facial proportions seem to be influenced by the overall perception of the face as human-like, e.g. enlarged eyes in virtual or doll faces or faces with lower photorealism did not cause an uncanny valley effect (MacDorman et al., 2009; Seyama & Nagayama, 2007), participants were able to more reliably identify ideal proportions in faces that received high ratings in human-likeness and attractiveness (Green et al., 2008), and participants showed decreased tolerance for distorted facial features as ratings of attractiveness increased (Green et al., 2008). Moreover, matching levels of photorealism (for different regions of a face) were rated more positively and mismatching ones were rated as more eerie (MacDorman et al., 2009).

Furthermore, atypical features in faces such as one distorted eye seem to cause uncanny reactions, because greater feature atypicality, combined with less human-likeness, resulted in higher eeriness ratings (Burleigh et al., 2013). With regard to categorical perception, a number of studies applied discrimination and identification tasks and rather coherently showed results supporting the assumption of uncertainty at category boundaries as indicated by decreased accuracy, higher response latency, and increased decision uncertainty (Cheetham et al., 2011; Cheetham et al., 2013; Yamada et al., 2013). Besides, when reaching the category boundary distinct facial features seem to be of greater importance than others, for instance participants looked more at the eyes than at the mouth or nose of morphed faces at the category boundary (Cheetham et al., 2013).

Mismatches of appearance and voice

Further evidence for a category conflict comes from Mitchell et al. (2011). In contrast to the majority of experimental work on the uncanny valley this study did not focus on mismatched visual elements, but on the mismatch of appearance (human vs. robot) and voice (human vs. robot). Participants viewed videos with either matched (robot - synthetic voice, human - human voice) or mismatched stimulus conditions (robot - human voice, human - synthetic voice) and evaluated the character’s humanness, eeriness, and interpersonal warmth. As expected, the results that mismatched appearance and voice elicited greater feelings of eeriness.

Summary

With regard to ***mismatches between movement and appearance***, it was found that humans and robots elicit brain activity in areas involved in action observation, face-recognition and emotional processing. However, the amount of activation, the extent of the involved brain areas can vary with when comparing different types of robots or robots and humans. Moreover, perceived intentionality influences effects of motor resonance. It has been argued that these differences stem from “learning”, because humans have greater opportunity to associate the observation of human movement with the execution of corresponding actions compared to robotic movement (cf. Press, 2011).

Regarding ***mismatches between aspects of appearance***, previous research predominantly used morphed pictures to study uncanny valley related responses. Pictures were gradually (asynchronously) changed with regard to, for instance, facial proportions, texture, and photorealism. Overall perceived human-likeness, seems to increase uncanny valley related responses. For instance, enlarged eyes in virtual or doll faces or faces with lower photorealism did not cause an uncanny valley effect (MacDorman et al., 2009; Seyama & Nagayama, 2007) and participants more reliably identified ideal proportions faces that were perceived to be human-like and attractive (Green et al., 2008). There is empirical evidence that participants show uncertainty at category boundaries (for instance boundary between human category and virtual face category) as indicated by decreased accuracy in discrimination tasks, higher response latency, and increased decision uncertainty (Cheetham et al., 2011; Cheetham et al., 2013; Yamada et al., 2013). Moreover, facial features are increasingsly important at category boundaries.

Finally, also ***categorical mismatch across modalities*** can produce negative reactions (Mitchell et al., 2011). However, the empirical evidence for this is effect is rather limited.

4.3.2 Evolutionary-biological explanations

Evolutionary-biological explanations for the uncanny valley are based on the assumption that people are very sensitive to obvious, but also subtle, cues in other people that prevent us from physical threats as well as from negative preconditions for our offspring. MacDorman and Ishiguro (2006) refer to Rozin's theory of disgust (Rozin & Fallon, 1987; Rozin et al., 1999) in which disgust is described as an evolutionary developed cognitive mechanism to *avoid the risk of infection* and the risk of *genetically inadequate mating partners*. With regard to danger avoidance it is assumed that the more human-like an organism looks, the more sensitive we are for abnormalities indicating some kind of defect that might probably be dangerous for us. This is because species which are genetically closer are more likely to contaminate us with diseases. With regard to mate selection we especially observe indicators for fitness and fertility which are closely linked to *physical attractiveness.* Since android robots in particular very closely resemble human beings the "rules" of physical attractiveness are presumably are also applied when judging androids. Thus, it can be assumed that androids are uncanny to the extent to which they differ from the nature norm of physical attractiveness (MacDorman & Ishiguro, 2006). In this context Burleigh et al. (2013) discuss the atypical feature hypothesis (see also section II.4.3.1). They refer to Nesse (2005) who explains humans' sensitivity to atypical features in terms of cost-benefit functions for automatic defenses to threats which are calibrated to minimize false-positive errors at the expense of increasing false-negative errors. Given this mechanism we undermine the risk of falsely categorizing a threat as non-threatening by oversensitivity to these cues. However, the downside is that “if a feature on a conspecific stimulus is sufficiently atypical, then it can be expected to trigger one of these mechanisms independently of any real danger” (Burleigh et al., 2013, p. 760). This is expected to increase with increased human-likeness, because then the object will be more likely classified as conspecific. Schaller and Park (2011) call this set of mechanisms the behavioral immune system and note that “the system responds to an overly general set of superficial cues, which can result in aversive responses to things (including people) that pose no actual threat of pathogen infection” (Schaller & Park, 2011, p. 99), e.g. people with physical disabilities (e.g., limb amputation due to accident; Park et al., 2003; or people suffering from obesity Park et al., 2007). Finally, MacDorman and Ishiguro stated that these mechanisms lead to increased *salience of one’s own mortality* which can be investigated using techniques from terror management theory research (Greenberg et al., 1990). Consequently, a first study by MacDorman (MacDorman, 2005b, also reported in MacDorman & Ishiguro, 2006) addressed *mortality salience* as a possible explanation for the uncanny valley. MacDorman presented participants a picture of a young woman or a picture of a turned-off female android (alongside other stimuli) and attempted to show that the android reminded the subjects of their own mortality indicated by the emergence of distal defense reactions according to the terror management theory. Participants in the android group showed more distal defense reactions relative to the control group. However, the author discussed that these reactions apply to one particular stimulus, making it necessary to further investigate different stimuli. One limitation of this study is that apparently participants were not instructed that the picture showed an android thus they could have assumed that they saw a human on that picture. Indeed when asked after the experiment peoples’ comments on the picture lead to the assumption that some categorized the picture as a (scary, weird, sick, disturbing, dead, shocking; c.f. MacDorman, 2005b, p. 403) female human. In the study by Ho et al. (2008) which investigated which emotional statements are connected with the attributes creepy, strange and eerie during the perception of robots found no direct conclusion as to whether the uncanny valley is due to the fear of one’s own mortality or due to mechanisms for pathogen avoidance. As described in section II.4.3.1, besides the categorical perception hypothesis Burleigh et al. (2013) also addressed the hypothesis that uncanny responses are due to atypical features on otherwise typical human-like stimuli. They thus added atypical features in morphing continua. Although the author’s prediction that an atypical feature would elicit more eeriness at higher levels of human-likeness than at lower levels did not hold true, yet greater feature atypicality, combined with less human-likeness, resulted in higher eeriness ratings.

These studies are the only rare attempts to directly or indirectly address evolutionary-biological explanations for the uncanny valley. However, the assumption itself is very popular and has also been discussed in the context of motor resonance (e.g. distinguishing movement of conspecifics and possible predators or prey is crucial for avoiding danger and gaining resources).

4.3.3 Cognitive-oriented explanations

There is almost no work on the diverse cognitive-oriented explanations presented in section II.3.3. Similarly to the above introduced concepts of conflicting perceptual cues and categorical perception, Ramey (Ramey, 2005; Ramey, 2006) formulated that the categorization of all objects and events is obligatory for humans (cf. also Medin & Barsalou, 1990). Ramey sees this explanation in relation to *sorites paradoxes involving personal and human identity* (cf. section II.3.3; Ramey, 2005). Ramey states that the categorization of humanoid robots or androids into one of the categories “animate” or “inanimate” cannot be done easily and reliably, because they are at the boundaries between these categories. However, these category boundaries are not static. Thus there is the possibility that humans form a third category about humanoid robots through repeated contact and the dilemma might be resolved. This approach does not see the Uncanny Valley as a unique phenomenon only involving humanoid robots, but rather regards the uncanny valley as part of a class of cognitive and perceptive states of uncertainty at category boundaries. Admittedly, this explanation also has not been investigated sufficiently, but an initial study showed that participants were able to distinguish relatively clearly between the categories human and computer as indicated by very different characteristics named for these categories (Ramey, 2006). When participants were asked the same for humans and robot it became clear that humans and robots share a lot of characteristics, for instance the shape, size and number of limbs (e.g. 2 legs), facial features and sensory organs (e.g. eyes, ears, smile, mouth, nose), gender attributes (e.g. “male female parts”, “masculine figure like a male”). This is not surprising, because a lot of robots are built to resemble humans at least in parts. This is also reflected in that participants were more willing to transfer characteristics from their own category (human) to robots (see examples above), rather than transferring robotic characteristics to their own human category (e.g. lights as eyes, having a keyboard). A direct test of this explanatory approach as well as a test of the establishment of a third (new) category through habituation is missing.

Also rather cognitive-oriented explanations for the uncanny valley effect are *subconscious fears of reduction, replacement, and annihilation* which have been mentioned by MacDorman and Ishiguro (2006). MacDorman and Ishiguro speculate that androids might remind us of our own mortality or trigger the fear that we are all just soulless machines. Moreover, we might be replaced by robots. The theme of the doppelgänger is extremely present when discussing the development of android robots, especially as the most prominent examples of android robots are indeed copies of real humans. Together with the Kokoro Company Ltd., Prof. Ishiguro (Osaka University, ATR) developed and built android robots. The collaboration started with the production of the so called actroid series including Repliee R1 (a replication of Hiroshi Ishiguro's daughter), Repliee Q1 and Repliee Q2 which both resemble Japanese women in their thirties. The second series of android robots is the Geminoid series with the models: Geminoid HI-1 (a copy of Hiroshi Ishiguro), Geminoid F (a copy of a befriended woman of Ishiguro), and Geminoid DK (a copy of Henrik Schäfe, a Danish professor). As discussed in section 1.1 the connotation of the double changed during history from an "insurance of immortality to an uncanny harbinger of death" (Freud, 2003, p. 142). With regard to robots and androids the doppelgänger theme is also present in popular culture playing with our fear of being replaced in some way or not being unique. In the movie "Surrogates" (Handelman, Hoberman, Lieberman, & Mostow, 2009) people operate surrogates which replace them in their daily lives while the operators stay at home in order to avoid any threat and harm to their bodies. In this case the robots serve as avatars and do not have autonomy, but replace the physical body in daily interaction. Moreover, also robots and androids have "evil twins" or "evil doubles": Michael Knight and K.I.T.T. in Knight Rider are being chased by their evil twins Garth Knight and K.A.R.R. and Star Trek's Data faces his evil twin brother Lore. These stories always include that a good human (or also robot) is replaced by an evil counterpart and henceforth the good original is struggling to maintain or get back his or its identity. On a lower level –without the danger to one's own identity- there is the fear of losing one's own job to a robot. Indeed there are frequently reports in the news touching the question of whether we have to fear being replaced in our jobs (e.g. Aquino, 2011; Sherman, 2013) also leading to the discussion about ethical frontiers of robotics, for instance, application fields which are regarded as not appropriate (Sharkey, 2008; Sharkey & Sharkey, 2010a; Sharkey & Sharkey, 2010b). So far there is some research on anxiety towards robots with regard to their societal impact (Nomura, Kanda, Suzuki, & Kato, 2005;

Nomura, Suzuki, Kanda, & Kato, 2006; Nomura, Shintani, Fujii, & Hokabe, 2007; Nomura, Suzuki, Kanda, & Kato, 2007). However, there is still little known on how people feel about robots, why they regard some application areas as appropriate and others not, and whether humanoid and android robots elicit fears of being replaced. One way to avoid these questions are the increasing attempts to integrate current developments in robotics into society by, for instance, following principles of participatory design (e.g. Lee, Šabanović, & Hakken, 2013).

4.4 Related work on appearance, anthropomorphism, narration

As Ho et al. (2008) aptly stated: the uncanny valley is a “nexus of phenomena with disparate causes” (p.175) which becomes obvious when reviewing the work on all the different explanatory proposals. However, although diverse concepts have been addressed, other related concepts have been neglected by those researchers especially focusing on the uncanny valley. The following are not to be understood as a complete review of the research on the issues of appearance, anthropomorphism or narration in HRI, but shall provide a brief outline of important results to emphasize the importance of these related concepts.

4.4.1 Appearance and Anthropomorphism

With regard to the dimension “human-likeness”, appearance has been assumed as one of the most crucial factors. However, it has to be taken into account that a lot of work on the uncanny valley effect utilized virtual faces instead of actual robots. For virtual faces and android robots it can be assumed that humans will draw on similar criteria, as they experience in human-human encounters, when deciding whether they would like to interact again with a robot. In this regard (physical) attractiveness plays an important role. Here, the finding, ‘‘what is beautiful is good’’ (Dion, Berscheid, & Walster, 1972), in the sense that attractive people are also rated positively in other aspects can also be assumed to be true for virtual agents and robots. It has been shown that the same principles for judging attractiveness in humans hold for the judgement of attractiveness in virtual agents (Sobieraj, 2012). Thus, we know that artificial entities follow the same principles of physical attractiveness when they expose a closely human-like appearance. However, there is still little known on what exactly is perceived as beautiful when it comes to robots which are not android.

In this regard, DiSalvo, Gemperle, Forlizzi, and Kiesler (2002) examined what features and dimensions of a humanoid robot’s face contribute to people’s perception of its humanness. They analyzed 48 actual and fictional robot faces with regard to certain facial features (e.g. existence of eyes, nose etc., and relational features like width of head, eye spacing, mouth width, features height) and asked people to rate how human-like these robots were. They found that the more features a robot head possesses the more human-like it was perceived to be. Moreover, the width/height ratio of the head was important, because the wider the head in relation to its height, the less human-like it was perceived to be. Specific features that were most important for higher human-likeness ratings were the presence of a nose, eye-lids and a mouth. While these findings are really interesting they are limited to the heads of humanoid robots and do not address non-humanoid robots or robotic bodies.

Woods (2006) explored the design space of robots by asking children about their perceptions and evaluations of 40 robots with regard to their robot appearance, robot personality dimensions and robot emotions. Results showed that depending on a robot's appearance children clearly distinguished robots in terms of their intentions (i.e. friendly vs. unfriendly), their capability to understand, and their emotional expression. This is in line with other research linking robotic appearance with expected cognitive capabilities. It has been shown that a more human-like appearance elicits expectations about higher cognitive functions. Krach et al. (Krach et al., 2008, also reported in Hegel, Krach, Kircher, Wrede, & Gerhard, 2008; Hegel, Krach, Kircher, Wrede, & Sagerer, 2008) report that participants behaved in a way that they implicitly attributed increasing theory of mind like abilities in interaction with a personal computer, a functional robot, an anthropomorphic robot and a human in a prisoner's dilemma game task. With regard to the uncanny valley hypothesis, Gray and Wegner (2012) propose that the appearance of human-like robots prompts attributions of mind. They examined whether a robot with a human-like in contrast to a mechanical appearance elicits more ascriptions of experience (the capacity to feel and sense; in contrast to agency, the capacity to act and do) and negative responses. Indeed, greater experience was attributed to the human-like robot, but both robots received similar attributions of agency. Moreover, the human-like robot was perceived as more uncanny which was found to be predicted by ratings of experience attribution. Moreover, Gray and Wegner gave people narratives introducing a machine that is capable of either experience or agency or neither of them, similar narratives were given for a human person. They found that a machine (regardless of the not described appearance) was perceived as being most uncanny when it is capable of experience. Contrarily a human person received greatest uncanny evaluation when it is not capable of experience. The authors conclude that uncanniness is not determined by just appearance itself, but perceptions of experience and "also suggest that experience -but not agency- is seen as fundamental to humans, and fundamentally lacking in machines" (Gray & Wegner, 2012, p. 125).

Goetz, Kiesler, and Powers (2003) summarized after studies in which the appearance of robots were varied as well as the supposed jobs they shall be doing that people systematically preferred robots for jobs when the robot's human-likeness matched the sociability required in those jobs. Moreover, participants preferred those robots whose behavior matched the seriousness of a task (fun robot for playful task, serious robot for serious task). The results indicate that a robot's social cues should match its task to increase acceptance of the robot and willingness for cooperation with the robot.

Similar experiments prove the importance of appearance as they show that appearance frequently influences users' evaluations of and behavior towards robots (e.g., Carpenter et al., 2009; Chee, Taezoon, Xu, Ng, & Tan, 2012; Kanda, Miyashita, Osada, Haikawa, & Ishiguro, 2008; Komatsu & Yamada, 2007; Lohse et al., 2007; Robins, Dautenhahn, te Boekhorst, & Billard, 2004) and their expectations about task performance (Hinds, Roberts, & Jones, 2004; Li, Rau, & Li, 2010), and the agent's attitudes (Komatsu & Yamada, 2007).

Since the uncanny valley has been researched by scholars in the field of virtual agents or virtual characters and by scholars in the field of robotics, another important aspect of the uncanny valley is embodiment. There is ample work on whether robots and virtual agents elicit same, similar or different effects because of their virtual or physical embodiment (cf. Hoffmann & Krämer, 2011 for an overview). While the virtual figures are almost all quite human-like (or realistically animal like) in their appearance, when looking at robots it is clear that they show more variety in form (also due to the physical tasks they shall fulfill): robotic embodiments can range from ubiquitous technology devices like K.I.T.T. which is embodied only by his voice to fully human-like android robots like Commander Data, to name two fictional extremes (for a discussion cf. Rosenthal-von der Pütten & Krämer, 2013).

4.4.2 Narration

Mara et al. (2013) provided participants with a narrative framing for a subsequent interaction with the robot Telenoid (Ogawa et al., 2011). The robot was introduced either with a short story presenting the Telenoid as character or with a non-narrative information leaflet about it. A control group did not receive any prior information. In the story condition perceived usefulness and behavioral intentions to adopt the robot were significantly higher compared to the other conditions. The results indicate that stories could be used to increase user acceptance of new robotic agents.

4.5 Cultural differences in the perception and acceptance of robots

As discussed in section II.3.4 it has been proposed that the uncanny valley response could be different across cultures as well as be culturally dynamic and subject to change over time (e.g. Brenton et al., 2005; Gee et al., 2005). Indeed, research suggests cultural differences in the perception of robots and their acceptance. Bartneck, Suzuki, Kanda, and Nomura (2006) asked participants from the USA, Japan and Mexico about their negative attitudes towards robots and revealed that in contrast to the assumed stereotype, the Japanese were more concerned by the impact that robots might have on society than US Americans. Participants from Mexico, however, had the most negative attitude towards robots. Bartneck et al. discuss that Japanese are generally more exposed to robots in real life and in media and might therefore be more aware of the robots' abilities and their shortcomings. Based on the results of the "Uncanny Cliff" study (Bartneck et al., 2007) which only involved Japanese participants, Bartneck investigated the influence of gender and cultural background on likability and anthropomorphism ratings for different robots (Bartneck, 2008). The follow-up study included American and Japanese participants. As in the previous study, Bartneck used not only pictures of faces of real humans and androids, but also manipulated humans and computer graphics of humans. Results showed that the likability ratings of the US participants increased for increasingly anthropomorphic robots. For Japanese participants there was a reverse effect observable: they liked the toy robots and humanoid robots most. Thus, Bartneck concludes that the stereotype that Japanese like conventional robots has been confirmed. Moreover, he states that "The "uncanny cliff" […] we observed might have been limited to the Japanese culture. The strong preference for robots with a robot-like appearance might have formed the cliff. This may be explained by the strong presence of robots in Japanese popular culture, starting with Astro Boy" (Bartneck, 2008, p. 556). Similarly, MacDorman, Vasudevan, and Ho (2009) discuss East-West cultural differences and especially their roots in religion and philosophy. Shintoism derives from animism, the belief that things are inhabited by spirits. In Buddhism all things are considered to have intrinsic nature. In contrast Greek philosophy differentiated between human and nonhuman. And in monotheistic religions the creation of machines in "one's own image" can be seen as usurpation of God's role. MacDorman et al. also refer to the different reception of robots in media. While Japanese like the robotic comic hero Astro Boy, Western movies often feature robots which run amok. Although it has to be mentioned that there are at least as much movies depicting another picture (*Robots*, *Wall-E*, *Frank & Robot*, *Johnny 5*, *The Hitchhiker's Guide To The Galaxy*). Another issue raised by MacDorman et al. is that robots play an important role in Japanese economy and that Japanese are more exposed to robots. In their study, MacDorman et al. utilized implicit measures to investigate cultural differences in participant's attitudes towards robots. With two Implicit Association Tasks (IAT) MacDorman et al. assessed participants implicit attitudes towards robots. One test included silhouettes of humans and robots and positive and negative words and the other included the silhouettes of humans, robots, weapons and non-weapon objects. In addition, participants completed a short questionnaire. Results show that Japanese and U.S. participants did not differ greatly in their answers with regard to whether they prefer humans or robots, how warm or cold they rate both entities and how safe or threatening these entities are. The IAT test revealed no differences with regard to the implicit association of robot as pleasant or unpleasant. Both groups more strongly associated the human silhouettes with pleasant words than robot silhouettes and the robot silhouettes more strongly with weapons than the human silhouettes. Nomura et al. (2008) asked students from Japan, Korea, and the US about their thoughts and attitudes about robots with a focus on five factors relating to humanoid and animal-type robots: relative autonomy, social relationship with humans, emotional aspects, roles assumed, and images held. The authors summarize that students regardless of their nationality tend to assume that humanoid robots perform concrete tasks in society, while animal-type robots play roles related to pets or toys. In contrast to US and Korean students, Japanese students more strongly assumed that humanoid robots have somewhat human characteristics and assume roles which are related to social activities. Korean students differed from Japanese students in that they expressed more negative attitudes towards the social influence of robots and they see robots' role more strongly related to medical fields. Surprisingly, the US students expressed weaker assumptions about robots being blasphemous of nature than do Japanese and Korean students which contrasts the general assumption that with regard to robots, Japanese are positively biased because of their Buddhism and Shintoism influenced cultural background. Mavridis et al. (2012) asked people from 38 different countries about possible application areas for the android robot *Ibn Sina*. They found that in contrast to other regions (Africa, Europe, America, the Gulf) people from Southeast Asia and Sham countries had the most positive attitude towards being taken care of by a robot in hospital and people from Southeast Asia had the most positive attitude toward having their children instructed by robots at school.

Although scholars differ in their interpretation of the origins or in their estimation of the impact of cultural differences with regard to attitudes towards and assumptions about robots, a general tendency to assume cultural differences can be observed. Most often empirical work concentrates on the comparison of Japanese participants with participants from Western cultures, predominantly US Americans. The Japanese are especially interesting, because the per capita rate of robots is very high compared to most Western countries. Japan is also very advanced in the development, fabrication and implementation of robotic systems. The results of the studies examining cultural differences are mixed. Some studies indeed revealed differences (Bartneck et al., 2006; Bartneck, 2008; Mavridis et al., 2012; Nomura et al., 2008). These are, however, not consistent, because some promote differences according to the stereotype that Asian cultures are generally more in favor of technology and robots than Western cultures and some results suggest a reverse effect. Moreover, there are studies where no differences have been found (McDorman et al., 2009). Cultural differences seem to play a role with regard to the perception of robots, but the results are inconclusive. Thus, more research is needed to explore the role of cultural background with regard to the perception and acceptance of robots in general and the uncanny valley effect in particular.

5. Summary and research objectives

Considering the literature reviewed two general research lines are observable: first, work trying to emulate the uncanny valley graph and, second, work addressing possible explanations for the uncanny valley effect.

Studies which try to show the existence of the uncanny valley effect use rather simple methods to emulate the uncanny valley curve. These studies stick very closely to Mori's original graph of the uncanny valley with a gradually increasing curve which midway falls into a deep valley but then again increases. Depending on the stimulus material (morphed pictures, pictures of actual humans, robots and computer graphics as well as videos of actual robots) researchers were able to reproduce the graph (Lay, 2006; MacDorman & Ishiguro, 2006) or "intentionally failed" to produce it (Hanson, 2006; Hanson et al., 2005). These studies overall share the fact that they are affected by methodological shortcomings such as non-standardized stimulus material (MacDorman, 2006; Riek et al., 2009), a very limited set of stimuli (Bartneck et al., 2007; Riek et al., 2009), and that only descriptive results were reported (Hanson, 2006; Hanson et al., 2005; Lay, 2006; MacDorman & Ishiguro, 2006).

Empirical work on possible explanations of the uncanny valley effect does not stick very closely to the original graph, but rather sees Mori's hypothesis as a starting point to examine whether and if so why humans react negatively to increasingly human-like robots. Proposed explanations can be classified in three categories: perception-oriented, evolutionary-biological oriented and cognitive-oriented explanations. An analysis of the proposed explanations and their underlying concepts revealed that one phenomenon traverses different levels of perception and cognition that is that our perception and cognition is guided by categorization processes (Harnad, 1990; Stein & Stanford, 2008). Furthermore, in all these diverse research areas processes were mentioned which cope with discrepancies or deviations from expected or predicted input. Most often researchers refer to Festinger's theory of cognitive dissonance (Festinger et al., 1978) to emphasize that this mismatch causes cognitive dissonance which is subsequently negatively interpreted and held responsible for the uncanny valley effect (cf., Burleigh et al., 2013; Chaminade et al., 2010; Saygin et al., 2012). Some scholars explicitly point out that these coping strategies to deal with uncertainty can also arise for any other conflicting perceptual cues or for any other entities at category boundaries, not necessarily only for humanoid or android robots (Bartneck et al., 2007; Ramey, 2005; Ramey, 2006; Saygin et al., 2012). However, also the studies examining explanations are subject to certain limitations. There are two research areas, one using virtual characters and virtual faces and one using actual robots to investigate the uncanny valley effect. It is, however, questionable and not easily verifiable whether the results of both areas hold true for the other area respectively. For instance, with regard to categorical perception researchers frequently use virtual faces in their studies, because it is very hard to gradually change physical properties of actual robots. This makes a verification of these results quite hard, if not impossible. However, taking empirical evidence with regard to different embodiment (Hoffmann & Krämer, 2011) and its effect into account it can be assumed that "uncanny" effects could vary for virtual faces and robots, both in magnitude and quality. In conclusion, there is more work utilizing virtual faces than actual robots when investigating the origins of the uncanny valley effect. Furthermore, there is a misbalance observable in that a lot of work addresses the perception-oriented explanations, but much less work deals with evolutionary-biological or cognitive-oriented explanations.

Moreover, the quantity of explanations for the uncanny valley effect emphasizes the complexity of the underlying mechanisms. Thus, Mori's hypothesis has been consistently criticized as being too simplistic (Bartneck et al., 2007; Bartneck et al., 2009; Gee et al., 2005; Pollick, 2010) which resulted in a number of revised models. Along the same line, researchers state that factors inherent to the participants such as participants' age, culture, religion, or their previous experiences with robots have to be taken into account (Gee et al., 2005; Brenton et al., 2005; Ishiguro, 2006). However, this work also identified other relevant factors for the uncanny valley effect, such as aesthetics, sound, timing, and (social) context.

Some scholars (Bartneck et al., 2007; Brenton et al., 2005) rightly pointed out that observed uncanny valley responses might only be short-term effects whose actual impact could have been overestimated. So far there is no work addressing this concern. In addition, as most studies utilize only pictures and videos of robots no conclusions can be drawn on peoples' experiences in interactions with real robots.

Research Objectives

Altogether, a number of open questions have been identified within this work, some of which will be addressed within this research in the course of four consecutive studies. In the following, the open questions will be summarized and an outline is given on how the present project will contribute to their examination.

First, more work is needed on the question of *how different kinds of robots are perceived* with regard to dimensions relevant for the uncanny valley hypothesis. To fill this gap first qualitative interviews (Study 1) will explore whether all human-like robots are perceived negatively, and if yes, what reasons are mentioned by participants. The analyses will also include what positive aspects are mentioned by participants and thus provide a holistic view on how very human-like robots are perceived and why they are perceived as such from the perspective of the participants. Moreover, the project will aim at identifying certain characteristics of appearance which contribute to positive or negative evaluations on the basis of standardized material of actual robots (Study 3a, 3b and Study 4).

Second, with regard to the attempt of *reproducing an uncanny valley effect* (especially the graph) research is needed using standardized material of actual robots. Moreover, more sophisticated analyses are needed which go beyond the mere description or graphical depiction of curves, but critically discuss how well the data fits the proposed uncanny valley effect and thus allows conclusions about the actual suitability of the proposed uncanny valley curve. These aspects will be addressed in Study 3 and 4 of this research project.

Third, it has been suggested that movement aggravates uncanny valley related responses. Thus, it will be examined *how movement influences participants' perceptions of and behavior towards robots*. This will be pursued on the one hand with exploratory analyses based on very diverse material in the qualitative interviews (Study 1), and on the other hand in a more controlled field experiment in which the influence of an android's movement (still vs. moving) on participants' perception of the android and their behavior towards the android can be examined more systematically (Study 3).

Fourth, it is unclear what exactly an uncanny valley related reaction is. Reading the literature carefully, it becomes clear that it is often assumed implicitly that the uncanny valley is a negative emotional reaction. Different measures (self-report, behavior, psychophysiology) have been used separately to explore the phenomenon, but not all are adequate to draw conclusions on whether the observed reactions were emotional. However, a combination of these measures might provide deeper insights into the nature of these reactions, for instance, whether *uncanny valley related reactions stem from perceptual or emotional processes*. The research project will address this question by using different methodologies. In interviews participants will be a) directly asked to indicate whether they experience emotional states or not (Study 1) and b) it will be examined whether people report unrequested about negative experiences when encountering an android robot (Study 2). Moreover, the project aims to clarify whether brain regions responsible for emotion processing are relevantly involved during the perception of humanoid and android robots (Study 4).

Fifth, an important and necessary step is to *systematically test the above-presented explanations for the occurrence of the uncanny valley*. So far, there is an imbalance in that a lot of work addresses the perception-oriented explanations, but much less work deals with evolutionary-biological or cognitive-oriented explanations. Hence, cognitive-oriented explanations will be addressed during the qualitative interviews (Study 1), for instance, by asking participants' about fears related to human-like robots or how they categorize robots and humans. Evolutionary-biological explanations will be in the focus of Study 4, which will examine whether uncanny valley related reactions are induced by disgust. Further, the forth experiment will investigate how humans and robots are perceived not only with regard to self-report, but also with regard to neural activation during evaluation of and decision-making about these stimuli. By using standardized material of actual existing robots and humans this study will enhance the state of knowledge with regard to the examination of perception-oriented explanations.

Finally, it has been proposed that *participants' age and culture have an influence on their perception and evaluation of robots*. Thus, the effects of age and culture will be explored in qualitative interviews, where samples are chosen accordingly. Moreover, social context seems to be of important. This issue will also be reflected in the interviews (Study 1) by the choice of video material showing robots in diverse social contexts.

Some of the research gaps identified in the summary will not be addressed in this research project, for instance, the question whether uncanny valley reactions are only short-term phenomena. In order to investigate this question appropriately, one has to know first whether there are uncanny valley reactions, how they can be reliably measured and where they stem from. Only when these gaps are filled future research can examine whether these effects are short-term and can be overcome under certain circumstances. Moreover, some of the issues raised will need further investigation beyond this research project. For instance, although the qualitative interviews will look into age and cultural differences in the perception of robots, this will be limited to two age groups and people from only two cultural backgrounds. Further systematic research will be needed to draw conclusions on how culture influences how people perceive robots, what their attitudes are about robots and how they behave towards robots.

III. STUDY 1: A HOLISTIC VIEW ON INDIVIDUALS' EVALUATIONS OF AND ATTITUDES TOWARDS POSSIBLY UNCANNY ROBOTS USING QUALITATIVE INTERVIEWS

1. Introduction

The literature review developed the many remaining open questions with regard to the uncanny valley phenomenon. The goal of this first study is to address a considerable part of these questions in one comprehensive interview in order to gain a holistic view of participants' attitudes towards robots in general, their perceptions and evaluations of different humanoid and android robots in particular and to derive first conclusions with regard to possible causes and explanations of the uncanny valley. The interview will be designed to take account of the leading questions presented at the end of the literature review (section II 3.5).

First, whether participants report about emotional reactions to different robots will be explored. Previous research showed that people indeed report about positive and negative emotional states in human-robot interaction, for instance after seeing a dinosaur-shaped robot in affectionate or violent interactions and also showed increased psychophysiological responses (Rosenthal-von der Pütten, Krämer, Hoffmann, Sobieraj, & Eimler, 2013). However, Rosenthal-von der Pütten et al.'s study involved video material explicitly tailored to trigger empathetic reactions and in contrast, most pictures and videos used in the studies examining the uncanny valley effect use rather neutral pictures with no interaction. Thus, it will be explored whether participants report about feelings when seeing pictures and videos of humans and which valence these feelings have. Moreover, according to the uncanny valley hypothesis by Mori the android robots per se should elicit negative perceptions and evaluations, but results from interview studies do not suggest a general aversive tendency against androids (e.g. Carpenter et al., 2009). Therefore, the interviews will look into the question of how humanoid and android robots are perceived and evaluated and what participants name as the reasons for their perceptions. The related research questions are:

RQ1: How do participants react towards the different robots?

RQ2: Do participants mention any reasons for negative evaluations, especially any fears or anxieties? If yes which fears and anxieties?

Within the uncanny valley hypothesis movement plays an important role, because it amplifies the uncanny valley effect. The interviews will concentrate on this factor in that participants will be presented both pictures and videos of different robots in order to track down shifts in perceptions and evaluations due to movement. Another important aspect is appearance. The dimension of human-likeness has often been operationalized solely on the basis of appearance excluding for instance human-like communication abilities. Moreover, the importance of physical characteristics has also been addressed in previous work. For instance, Carpenter et al. (2009) conducted semi-structured interviews centering on the question of the influence of gender representation of humanoid and android robots, given that some robots are designed with obvious gender orientation while others are less distinct. The authors found that human-like characteristics triggered gender-related issues in the discussion. Such triggers could be the voice, clothing or the morphology of the robot (android shape). Robot gender associations were parallel to human gender associations, for instance according to human gender stereotypes participants showed preferences for a female robot for in-home use. Moreover, Dautenhahn et al. (2005) report that human-like appearance and behavior was not the most important characteristic for their interviewees, but human-like communication abilities were important. However, especially interesting when regarding android robots is the fact that the same principles for judging the attractiveness of humans hold for the judgment of attractiveness for virtual agents (Sobieraj, 2012). Thus, we know that artificial entities follow the same principles of physical attractiveness when they expose a closely human-like appearance. Against the background of these findings, the interview will address the possible importance of physical characteristics and the relative physical abilities of robots. Accordingly, the research questions are:

RQ3: How important is the aspect of movement with regard to the perception and evaluation of these robots?

RQ4: Which physical characteristics and which abilities are associated positively and which are associated negatively?

When using videos of robots the aspect of the context of human-robot interaction also becomes important. For instance, MacDorman (2006) was not able to replicate an uncanny valley effect presumably because the videos he used were too diverse with regard to the contexts in which robots were presented. Thus, in the present study robots will also be presented in diverse contexts to specifically explore the influence of context. Moreover, possible human-robot interaction scenarios and application fields will be discussed. With regard to the latter, some previous studies featuring interviews addressed the question of suitable application fields and concentrated on roles robots could take on (service, assistant, butler, or companion). Carpenter et al. (2009) found that robots for in-home use were seen in an assistive role and should be designated to take over menial tasks such as household chores. However, Carpenter et al. also observed that many participants named roles they envisioned the robots fulfilling apart from those possible in homes such as receptionist, librarian or doctor's assistant. Dautenhahn et al. (2005) asked participants about their attitudes towards potential robot companions for in-home use. The authors also found that participants saw robots in the role of an assistant or servant designated to concentrated on household chores, gardening or guarding the house. In both studies participants showed averseness to robot roles and functions that concentrate on long-term and intimate social interaction such as childcare, caring for an animal, and companionship. Carpenter et al. reported that "frequently, participants fluctuated in their opinion, often within sentences, about whether they would want a robot to take care of their child or act in a purely social way" (Carpenter et al., 2009, p. 264) indicating conflicting opinions or attitudes of the participants. The concerns raised by the participants were that children might confuse robots with humans or animals (depending on the shape) and that expressing human-like emotion is faked. Moreover, Dautenhahn et al. report that human-like appearance and behavior was not the most important characteristic for the interviewees, but human-like communication abilities were important. Lohse et al. (Lohse et al., 2007) asked participants in online questionnaires open questions with regard to possible application fields for different robots after seeing a short video of them. Similar to Carpenter et al. they found that the appearance of the robots influenced the user's expectations leading to very different application areas proposed for zoomorphic, humanoid or mechanic robots, for instance the more functional robot BIRON was seen as an information terminal or guide while the dog-shaped robot AIBO was attributed roles and tasks which match those of a living dog like playing games, guard dog, guide dog, fetch and carry tasks. In general, the zoomorphic robots were perceived as more likable. Interestingly, Lohse et al. report a finding with regard to the humanoid robot BARTHOC which might be related to the uncanny valley effect: "Seven participants stated that BARTHOC could be used for a horror film or haunted house, because they thought that his appearance was very frightening. We think these comments are rather ironical than useful applications. Nevertheless, they are a hint that we have to keep working on the appearance of BARTHOC." (Lohse et al., 2007, p. 124). Altogether, it seems that context influences how robots are perceived and that appearance might be a trigger for suitable and unsuitable context. Accordingly, the research question is:

RQ5: How important is the context with regard to the perception and evaluation of robots?

During this interview study possible explanations of the uncanny valley will explored. Since participants will be aware of the course of the interview and have enough time to think about their answers, the interview questions will not deal with the perception-oriented or evolutionally-biological explanations (cf. sections II.3.1 and II.3.2) which involve subconscious processes, but will rather concentrate on the proposed cognitive-oriented explanations (cf. section II.3.3). Interview questions will address Ramey's (Ramey, 2005, Ramey, 2006) argument that the uncanny valley results from *uncertainty at category boundaries*. Thus, interview questions will ask for participants' conception of a robot category and how this may be distinguished from the human or machine category. Moreover, the interview questions will allude to the topic of *subconscious fears of reduction, replacement, and annihilation* (MacDorman & Ishiguro, 2006) which might be triggered by android robots. The related research questions are:

RQ6: What does the stereotype of a robot look like and what is the participants' general attitude towards robots?

RQ7: Can any conclusion be drawn on the causes of the uncanny valley, especially with regard to the explanations mentioned by MacDorman (fear of being replaced) and Ramey (category boundaries)?

Unanimously, researchers state that factors inherent to the participants such as participants' age, culture, religion, or their previous experiences with robots have been neglected so far when speaking of the uncanny valley and have to be taken into account (Gee et al., 2005; Brenton et al., 2005; Ishiguro, 2006). Previous research showed for instance that women evaluate robots differently from men (Schermerhorn, Scheutz, & Crowell, 2008) and a number of studies addressed the influence of (Western versus Eastern) culture with regard to the uncanny valley hypothesis (Bartneck et al., 2006; Bartneck, 2008; Mavridis et al., 2012; Nomura et al., 2008). Moreover, participants' experiences with regard to technology or their training respectively could have an influence. Thus, these aspects will be addressed in the interviews as well. Accordingly, the research questions are:

RQ8: Are there cultural differences in the perception and evaluation of these robots?

RQ9: Are there gender differences in the perception and evaluation of these robots?

RQ10: Do engineers perceive and evaluate robots differently from non-engineers?

Ishiguro (2006) suggested that the uncanny valley might be age-dependent and strongly linked with different developmental states. Implicitly Ishiguro refers to the development of categories and argues that especially young children will react fearfully to androids, because they have developed a human model, learned to apply this human model and started to be sensitive to mismatches, whereas adults can explain through their acquired knowledge that an android cannot fulfill their expectations of a human model and thus will not react with fear. Very young children or babies, however, had not yet developed a good model of others. Studies by Woods, Dautenhahn, and Schulz (2004) and Kahn et al. (Kahn et al., 2012) showed that, depending on the age of the children and on the appearance of the robots called into question, children believed that robots have mental states and can experience feelings. Kahn et al. showed that this belief decreases with increasing age. Both results suggest that children of different ages categorize robots differently and subsequently might also perceive and evaluate robots differently. Moreover, in interviews younger people tended to be more positive about robots for in-home use, whereas elderly people were more skeptical about this issue (Scopelliti, Giuliani, D'Amico, & Fornara, 2013), indicating that attitudes towards robots might also be subject to change along with participants' age. Therefore, the following research question is posed

RQ11: Do children categorize, perceive and evaluate robots differently from adults?

2. Method

In this study, semi-structured qualitative interviews were conducted to explore in more depth the uncanny valley and possibly related phenomena and aspects. During the course of the interview participants were presented with pictures and videos of humanoid and android robots followed by questions with regard to the participants' feelings and attitudes towards the presented robots. Furthermore, a series of questions dealt with higher cognitive and cultural aspects of negative responses towards robots. Below, the two samples (adults and children) are presented in detail followed by the presentation of stimulus material, interviewer guidelines and an explanation of the analysis of the interview data.

2.1 Participants and procedure

In total 38 adults and children participated in this study. Since recruiting and the method of conducting the interviews differed slightly between the samples, they are described separately in the following.

2.1.1 Sample 1: German and Malayan adults

The sample includes 16 adults; eight Malay and eight German (cf. Table 1). From each cultural group four participants were engineers and 4 were non-engineers. While for the German sample gender was balanced, in the group of Malayan participants there were three female and just one male participant in the non-engineers and one female and three male in the engineers' group. Participants were aged between 27 and 68 years of age with an average age of 33.15 years (SD = 12.22). Three female Malayan participants refused to state their exact ages, but since they were all PhD holders and worked as lecturers the author assumes that they were all in their mid-thirties. German participants were recruited via general advertising on campus at the University of Duisburg-Essen and the nearby University of Düsseldorf and via private contacts. Malayan participants were recruited via general advertising on campus at the Universiti Kebangsaan Malaysia with the help of the UKM Mercator Office & Multimedia Lab which supports collaborations between the UKM and the University of Duisburg-Essen.

Upon arrival participants read and signed informed consent. The following interview was video recorded or audio-recorded, respectively. At the beginning of the interview participants were asked general questions regarding their attitudes towards robots. Subsequently, participants were presented with pictures of six different robots in random order (cf. section III.2.2 for details), which were discussed separately. Afterwards, participants saw videos of these six robots in the same order as the presentation of the pictures. Again, each video was discussed separately. The interview concluded with a second set of general questions. Participants were debriefed and thanked for their participation.

Table 1: Age, gender, profession and culture of adult participants

German participants

Abbreviation for subject	Engineer	gender	Field of study/work	age
Ge1	no	male	Social science	28
Ge2	no	male	Social science	30
Ge3	no	female	Social science	28
Ge4	no	female	Political science	32
Ge5	yes	male	Engineering	68
Ge6	yes	male	Business informatics	28
Ge7	yes	female	Business informatics	28
Ge8	yes	female	Business informatics	23

Malayan participants

Abbreviation for subject	Engineer	gender	Field of study/work	age
Ma7	yes	male	Engineering	39
Ma8	yes	male	Computational mechanics	27
Ma1	yes	female	Wireless communication	28
Ma4	yes	male	Media studies, Engineering	47
Ma2	no	male	Physics	25
Ma3	no	female	English Studies	35
Ma5	no	female	English Studies	35
Ma6	no	female	English Studies	35

2.1.2 Sample 2: German children in two age groups

Moreover, the sample comprised 22 children in two age groups. Eleven interviewees were between 5 and 7 years of age and the other eleven participants between 10 and 11 years (cf. Table 2). Participants were recruited via advertising emails to friends and Facebook, as well as through the contact with a local elementary school. The school children were given an information letter for their parents. Those parents who were interested in letting their child participate, received, read, and signed informed consent. Interview appointments were arranged with the help of the teacher during the afternoon lessons in a room next to the class. Interested parents of pre-school children were informed via telephone. Interviews took place at the children's home where their parents first read and signed informed consent. Parents were present during the interviews. All 22 children were interviewed by two student assistants who had received training in conducting interviews with children. The interviews were video recorded or audio-recorded, respectively. At the beginning of the interview participants were asked to paint a picture of a robot and answer general questions regarding their attitudes towards robots. Subsequently participants were presented with pictures of six different robots in random order (cf. section III.2.2 for details) which were discussed separately. Then participants saw videos of these six robots in the same order as the presentation of the pictures. In contrast to the adults' interviews, the children did not discuss the videos in order to keep the interviews within a reasonable time frame. The interviews were concluded with a second set of general questions.

Table 2: Age and gender of underage participants

	Gender	
age	**male**	**female**
5-7	4	7
10-11	5	6

2.2 Stimulus material

During the interviews participants were presented with pictures of three humanoid robots, Asimo, AR (Assistive Robot), and Nexi, and three android robots, CB2, HRP-4c, and Geminoid HI-1 (cf. Figure 13) in random order. Each picture was followed by questions with regard to the participants' feelings and attitudes towards the robots presented (cf. section III.2.3 for details).

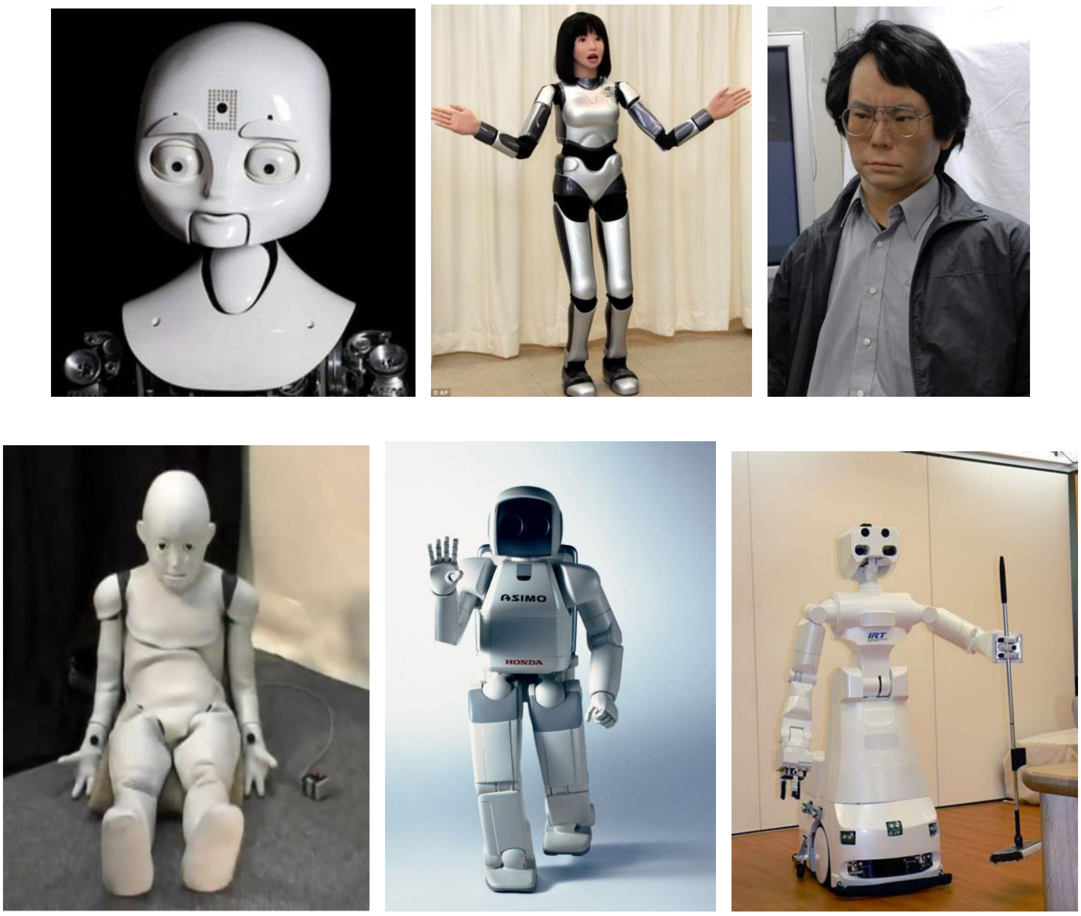


Figure 13: The six robots used as stimulus material in the interviews: Nexi, HRP-4c, Geminoid, CB2, Asimo & Robomaid (from the upper left to the lower right corner)

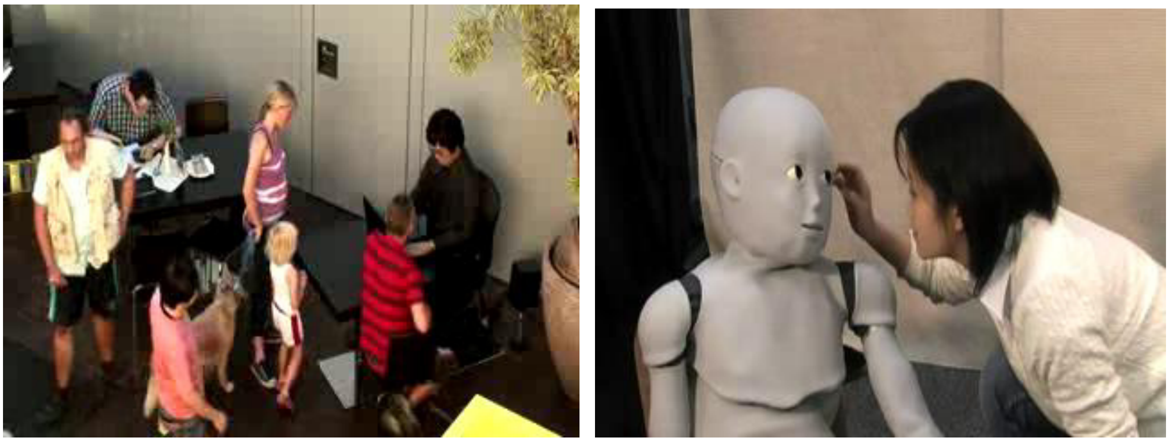


Figure 14: Snapshots of the videos showing Geminoid HI-1 (left) and CB2 (right)

Figure 15: Snapshots of the videos showing Asimo (left) and HRP-4c (right)

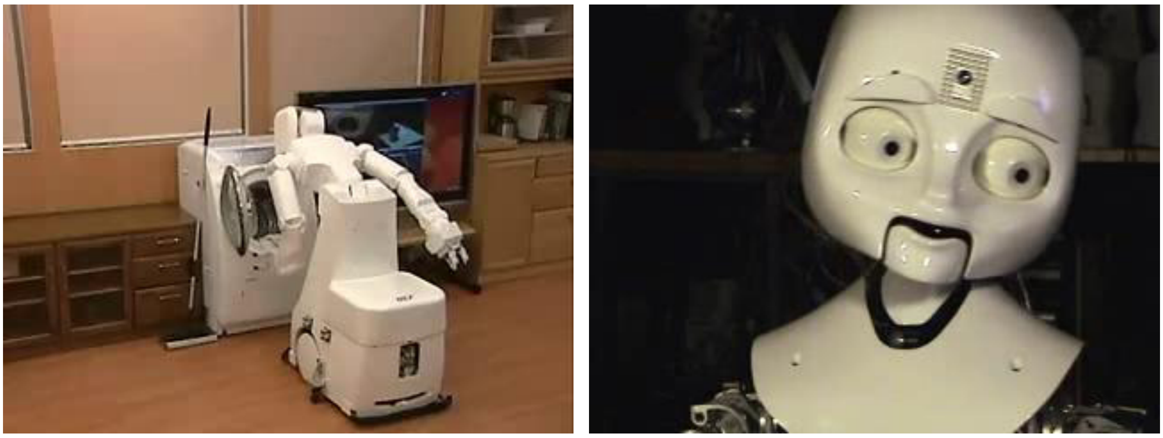


Figure 16: Snapshots of the videos showing Robomaid (left) and Nexi (right)

Afterwards the participants were presented with videos of these robots in the same order. Each video was about 30 seconds long. The videos showed the six robots in different contexts.

Geminoid: The video showed Geminoid HI-1 sitting in a café in front of a laptop. People were surrounding the robot and observing it. Two close-ups showed Geminoid HI-1's facial expression and his hands. (cf. Figure 14 left; the video was assembled from scenes of a Youtube video by Ramsy Gsenger: https://www.youtube.com/watch?v=ixhbXtfnE2k; further details on Geminoid-HI-1 can be found in Nishio, Ishiguro, & Hagita, 2007).

CB2: CB2 was sitting on the floor together with a human woman who touched CB2's head. CB2 established eye contact and blinked. The next scene showed CB2 lying on its back and moving like a toddler, e.g. rolling on its back, bringing knees to its chest, etc. (cf. Figure 14 right; video was assembled from scenes of a YouTube video by the JST ERATO Asada

Project and Kokoro Co. Ltd: https://www.youtube.com/watch?v=rYLm8iMY5io, further details on CB2 can be found in Minato et al., 2007).

Asimo: Asimo was standing in front of an orchestra and waved to the audience. The audience laughed. Asimo turned to the orchestra and began to conduct a musical piece (cf. Figure 15 left; the video was assembled from scenes of a YouTube video by the YouTube user marymag: https://www.youtube.com/watch?v=ScIEoZY3P18; further details on Asimo can be found in Sakagami et al., 2002).

HRP-4c: First the video showed a close-up of HRP-4c while the android was singing a Japanese song. Then HRP-4c was dancing to pop music accompanied by some human background dancers (cf. Figure 15 right; the video was assembled from scenes of two YouTube videos by Kazumichi Moriyama: http://www.youtube.com/watch?v=xcZJqiUrbnI and diginfonews: http://www.youtube.com/watch?v=_migLQ802Go; further details on HRP-4c can be found in Kajita et al., 2011).

AR: A newscaster gave a commentary on a video of AR showing its functionality. AR lifted a tray and took it to another place in the kitchen; it put laundry into the washing machine and mopped the floor. The newscaster mentioned the robot’s ability to perceive in a three-dimensional form and also its weight. There was a close-up of the robot’s head showing four built-in cameras (cf. Figure 16 left; the video was assembled from scenes of a YouTube video by ntdtv: http://www.youtube.com/watch?v=G5Vd9k3-3LM; further details on Home Assistant Robot AR can be found under http://www.jsk.t.u-tokyo.ac.jp/research/irt/ar.html and in Yamazaki et al., 2010)

Nexi: Nexi drove into the scene and introduced itself with its name. Then Nexi reported briefly about its capabilities (e.g. Nexi is mobile, can touch things, can communicate; cf. Figure 16 right; the video was assembled from scenes of a YouTube video by MIT’s Personal Robots Group: http://www.youtube.com/watch?v=aQS2zxmrrrA; further details on Nexi can be found under http://web.mit.edu/newsoffice/2008/nexi-0409.html and http://robotic.media.mit.edu/projects/robots/mds/overview/overview.html).

Each video was followed by questions with regard to the participants’ feelings and attitudes toward the robots presented (cf. chapter III.2.3 for details).

2.3 Interviewer guideline

The interviewer conducted *semi-structured* interviews according to the manual described in the following. Participants were free to answer as long as they wanted to. There were no time constraints. If they did not understand a question, the question was repeated. In general, the interviewer was urged to explain questions when necessary without inducing an answer. In order to receive deeper insights, interviewees were sometimes asked to elaborate on their answer if they answered with very short statements. Again the interviewer was urged to check with the participants without inducing an answer (e.g. neutrally ask "Why do you think you feel like this?").

In order to assess participants' general attitude towards robots and their stereotype of a robot (*RQ6*) they were asked some general questions at the beginning of the interview:

General questions at the beginning:

1. Please think of a robot in general. What crosses your mind at first? What can the robot do in your imagination and what does the robot look like? Please describe the robot you see in your imagination in detail.
2. When you think about the robot you described, how human-like would you say this robot is?
3. When you think of robots in general, how do you feel about this topic?

Furthermore, interview questions were posed to examine how participants react towards the different robots (*RQ1*) and whether they mention any fears or anxieties (*RQ2*). Thus the following questions were posed after the presentation of each picture:

Questions with regard to robot picture (separately for each robot)

4. How do you feel, when you look at this picture?
5. Are you relaxed or tense when you see the picture?
6. Imagine you are in the cinema and the robot in the picture was sitting right next to you. How would you feel about this?
7. What do you think the robot would feel like if you touched it?
8. When you look at the robot in the picture, does the robot look more familiar or more eerie/weird/uncanny/unfamiliar?

To explore the aspect of context, videos of all robots were presented showing them in very diverse contexts. All robots showed some movement, also varying with the context of the video. The following questions were asked in order to explore which physical characteristics and which abilities are associated positively and which are associated negatively (*RQ4*) and to explore the importance of context (*RQ3*) and movement (*RQ5*) in the perception and evaluation of these robots:

Questions with regard to robot video (separately for each robot)

9. How do you feel when you watch this video? (Interviewer asked for general valence of feeling and for perceived safety/uncertainty.)
10. What do you think about the robot in the video? (Interviewer asked for general valence of evaluation and perceived usefulness of the robot.)
11. What features and characteristics does the robot have?
    a. Was there something special about the robot, a special feature or characteristic?
    b. Did you miss a feature or characteristic that you think would be important to have?
12. You have already seen the picture of this robot. After watching the video please imagine again that the robot is sitting next to you, for instance, in the cinema. How would you feel?
13. How do you evaluate the robots movements?
14. Did the movements match to your expectations of robotic movements?
15. What could this robot do for you in your everyday life?
16. Would you buy this robot if you had enough money to afford it?

At the end of the videos, participants were asked to evaluate all the robots and answer some general questions about their evaluation criteria (*RQ4*). Moreover, they were asked questions which are tangent to the more cognitive-oriented explanations for the uncanny valley phenomenon proposed by Ramey (2005; 2006) and MacDorman (MacDorman, 2005b; *RQ7*). Thus the following questions were asked:

After watching all the videos, participants were presented with all the pictures in a pile and asked

17. Please put these robots in order with regard to their likability. On your right you should lay the robot which you like the most. Please explain why you put the robots in this order? Can you give reasons for your decisions?
18. If you had the possibility of meeting one of these robots, which one would you like to meet?
19. How important for you were different parts of the body or characteristics with regard to their likability?
20. Which field of application or for which tasks can you imagine these robots could be used in/for?
21. Can you think of any application fields in which you would not like to see robots? Where you would find robots inappropriate, annoying, and not useful? (Interviewer proposed the following three examples: carer for children, carer for a dog, hospital nurse, teacher)

22. How would you feel, if I now say that I am a robot? Imagine I am a robot, how do you feel about this?
23. If a robotic doublegänger of you were possible, would you like to have one? A robot that looks just like you?
24. When you look back on our interview:
    a. What distinguishes a robot from a human?
    b. What distinguishes a robot from a machine?

2.4 Analysis

Audio and video recordings were transcribed using the software f4 (http://www.audiotranskription.de/f4.htm). Utterances were transcribed verbatim and captured every word said during the interview. Thinking pauses were transcribed using ellipses (three dots: …). Non-verbal behavior (laughing) was transcribed. Fillers (uhms, ahs, you knows) were omitted. The Malayan Interviews were corrected for grammatical mistakes to facilitate understanding of the quotes used in further analysis. For the German sample quotes of interest which are reported in the results section were translated into American English.

The interviews were coded with MAXQDA software for qualitative data analysis (VERBI GmbH) using a coding scheme which was developed *deductively* according to the semi-structured questionnaire for most questions (cf. Table 3). For example, the questions asking for emotional reactions were coded with regard to their valence in the sub-categories *neutral*, *positive*, and *negative*; and regarding the question asking for the quality of a robot's movement, the answers were coded as indicating *low, medium* or *high quality.* In addition, for some questions, categories were derived *inductively* on the basis of participants' answers (questions 6, 7, 12, 24a & 24b: the cinema question after picture and after video, the question asking for haptic experiences, the questions asking what distinguishes robots from humans and machines, respectively). A coding unit can either be a single statement (sometimes only one text line, e.g. a very short answer to the previous question like "I feel negative.") or a series of answers resulting in one coherent statement (e.g. multiple statements to answer one question inclusive of interrupting interviewer comments ("hmhm", "okay") or interviewer requests ("Can you explain why?"); for further information cf. the coding manual in the appendix A). With few exceptions (multiple codings were possible for every open ended question, cf. coding scheme in Table 3), every code could be used only once in the document. If one topic or question was discussed twice in the course of the interview, the former was coded. Sometimes a question was omitted or participants did not answer a question directly, but concentrated on other topics which caught their interest. These cases are missing values and referred to as "no statement" in the results section. Of the sixteen interviews, four have been coded by a second rater. Inter-rater agreement was shown to be almost perfect (Cohen's Kappa= 0.85). The following coding scheme presents all questions asked during the interview with the possible codes, an according definition for these codes and explaining examples from the transcripts. When multiple codings were possible this is stated in parentheses after the question.

Table 3: Coding scheme for semi-structured interviews

Code	Definition	Key words or phrases from transcripts
When you think about the robot you described how human-like would you say this robot is?		
Not human-like	*Not human-like* / under 10 %	“Not at all”; “I’d say 2,3 or 4 %”
A little human-like	*Little human-like* / 3-6 on a scale / between 30 & 60 %, description of human-like features	“little human-like”; “Okay, if the car were not human-like, then a robot would be on a 3 and the 10 would be the human”
Very human-like	*very human-like* / 7-10 on a scale / everything over 60 %	“Very human-like”; “It’s like human in a machine form.”; “Maybe if I scale one to ten on a eight.”; “70 percent, I’d say”
When you think of robots in general, how do you feel about this topic?		
very positive	Any comment indicating an attitude towards robots which is stated as very positive; enthusiasm about technological advance	“very positive“; “fascinating“; “definitely positive“
rather positive	Any comment indicating an attitude towards robots which is stated as rather positive	“I think that I rather… technological advance…have a rather positive attitude towards this.”
neutral	Any comment indicating an attitude towards robots which is stated as neutral	“I think it’s okay.”; “I have no feelings, it is neutral”
rather Negative	Any comment indicating an attitude towards robots which is stated as rather negative	“they might be dangerous, depending on the programming”; “rather negative”
very negative	Any comment indicating an attitude towards robots which is stated as very negative; anxiety towards technological advance	“very negative”
How do you feel, when you look at this picture?		
neutral	Any comment indicating experiences of neutral feelings	“No, I don’t have any feelings.”; “I would say: neutral?”
negative	Any comment indicating experiences of negative feelings	“This elicits rather not so good feelings.”
positive	Any comment indicating experiences of positive feelings	“I don’t feel threatened or so. I am relaxed and curious.”
problems to express feelings	Any comment not explicitly indicating experiences of feelings; or description not directly referring to feelings	“But… a bit… perhaps I feel observed a bit.”
Are you relaxed or tense when you see the picture?		
relaxed	Any comment indicating that the participant feels relaxed or comfortable	“relaxed”; “I do not feel frighten. I think I will be quite relaxed.”
tense	Any comment indicating that the participant feels tense or uncomfortable	“tense”; “more tense than the one before”
neutral	Any comment indicating that the participant feels neither tense nor relaxed	“I’d say neutral again?”
Imagine you are in the cinema and the robot on the picture would sit right next to you. How would you feel about this?		
don’t care	Any comment indicating that the participant is not at all interested and does not care	“If he, he just sit there, Okay, no big deal.”
interested	Any comment indicating that the participant is mainly interested in the robot	“It makes me curious, like what’s it for?”
negative	Any comment indicating that the participant feels tense or uncomfortable or shows a negative reaction or antipathy	“Definitely weird”; “that would be an unpleasant surprise”
positive	Any comment indicating that the participant feels relaxed or comfortable or shows a positive reaction or sympathy	“I would love it.”
anxious	Any comment indicating that the participant experiences fear	“I would leave the place”

Code		**Definition**	**Key words or phrases from transcripts**
What do you think the robot would feel like if you touched it? (multiple codings possible)			
human-like		Any comment referring to human-likeness	“Feels like human”; “Like human skin”
mechanical (metal, plastic)		Any comment referring to mechanical appearance, e.g. metal, plastic	“On the top it is smooth and cold and at the bottom it is made of metal I think”
leather, silicone		Any comment referring to the haptic experience of some rather human-like material, e.g. leather or silicone	“It would be like a, for the parts so is a bit I think like the glove that you wear?”
hard		Any comment referring to hard texture	“hard somehow”
soft		Any comment referring to soft texture	“It looks very soft, isn’t it, right?”
cold		Any comment referring to cold	“In an air conditioned room it will be cold.”
warm		Any comment referring to warmth	“rather a warm feeling”
reluctance		Any comment referring to a general reluctance to touch the robot	“I would not like to touch it.”; “Why would I want to touch? No.”
uncertainty		Any comment showing uncertainty about what the robot feels like	“Okay, some parts would be... hm... I am not sure (laughs) how it feels. I can’t imagine.”
When you look at the robot on the picture, does the robot look more familiar or unfamiliar?			
familiarity	*familiar*	Any comment referring to the robot being familiar	“I would locate it closer to familiar”
	unfamiliar	Any comment referring to the robot being unfamiliar	“This is a strange looking robot.”
According to stereotype	*robot stereotype*	Any comment referring to the participant’s robot stereotype	“Because it is more near to the archetype robot features.”
	human stereotype	Any comment referring to the participant’s human stereotype	“This is more familiar, because at least the head is modeled after a human.”
How do you feel when you watch this video?			
valence	*positive*	Any comment indicating experiences of positive feelings	“I think more positive, yes.”
	negative	Any comment indicating experiences of negative feelings	“Also unpleasant.”; “Seriously, this is worse, this is worse.”
	neutral	Any comment indicating experiences of neutral feelings	“It is just like I am watching a technology.”
Safety, Uncertainty	*safe*	Any comment indicating experiences of safety, certainty	“Safe, it looks very small.”
	insecure	Any comment indicating experiences of uncertainty or insecurity	“Perhaps I did not experience *very* uncertainty, but it was uncertainty.”
What do you think about the robot in the video?			
valence	*positive*	Any comment evaluating the robot positively	“I would say I have a positive opinion.”
	negative	Any comment evaluating the robot negatively	“Okay, pleasant, not really, not really, because when you are looking at a person not wearing any clothes.”
usefulness	*useful*	Any comment evaluating the robot as useful	“The feature that she can touch things and communicate, it must be useful.”
	useless	Any comment evaluating the robot as useless	“I don’t really see the usefulness.”
How do you evaluate the robots movements? (quality of movement)			
low		Any comment evaluating the movement as being of low quality	“Still very stiff to me. Is robotic.”
medium		Any comment evaluating the movement as being of medium quality	“Okay? In general okay.”
high		Any comment evaluating the movement as being of high quality	“Fluent, calm and pleasant, yes.”; “The way it moves the hands as if like, I said, there is a human inside.”

Code	Definition	Key words or phrases from transcripts
Did the movements match your expectations of robotic movements?		
below expectation	Any comment evaluating the movement as being below the participant‘s expectations	“I expected that this have more natural movements.”
above expectation	Any comment evaluating the movement as being above the participant‘s expectations	“Exceeded expectation, yes.”
like expected	Any comment evaluating the movement as being just as expected	“I mean you expect it to be like that.”
What could this robot do for you in your everyday life?		
new example	Participant mentions a new application which is not the same as seen in the video	“Go into hazardous environments to help clean up” (AR robot)
same example	Participant mentions an application which is the same as seen in the video	“Mopping. I think the laundry, erm.” (AR robot)
nothing	Participants cannot imagine applications	“I can’t think of anything.”
Would you buy this robot if you had enough money to afford it?		
Yes	Participant would like to own the robot	“Why not?”; “That one? Definitely”
no	Participant would not like to own the robot	“No.”; “I wouldn’t know what to use it for.”
Can you think of application fields in which you would not like to see robots, where you would find robots inappropriate, annoying, not useful? Perhaps as director of an orchestra, house maid, interviewer, toy, carer for children, carer for a dog, hospital nurse, teacher?		
What distinguishes a robot from a human?		
Appearance	Any comment referring to the general appearance	“For the most part the appearance perhaps except the last robot (Geminoid HI-1) and the movement and maybe also the brain, that they don’t think like a human.”
Autonomy	Any comment referring to autonomous behavior and decision making	“Autonomous acting – robots don’t have this; emotions – they don’t have this and no creativity.”
Charisma	Any comment referring to charisma	“Soul, Geist, charisma, that all belongs together.”
Life-Cycle: Creation/Birth/ Mortality, Metabolism, Material (Flesh)	Any comment referring to the human life-cycle	“Humans can die and are born.”; “Material, mind, metabolism, and mortality.”; “Difficult. A robot is created artificially.”
Creativity	Any comment referring to the ability for creativity	“Autonomous acting – robots don’t have this; emotions – they don’t have this and no creativity.”
Emotion	Any comment referring to emotions	“Emotion. Robots have no emotions.”
Flexibility (humans)	Any comment referring to humans being more flexible than robots	“In comparison to humans, they are not so flexible. They are made for a specific purpose.”
Individuality	Any comment referring to individuality	“I believe, this self-awareness thing, the individuality and I don’t know that we are able to learn evolutionary.”
Learning (evolutionary, humans)	Any comment referring to learning	“I believe, this self-awareness thing, the individuality and I don’t know that we are able to learn evolutionary.”
Mind/Self-Awareness	Any comment referring to having a mind and self-awareness	“Mind, body, psychology right?”; “So I don’t want to have a robot that like can think on its own. I don’t want that, because you are not human kind of thing.”; “Definitely the brain I would say which includes how a human thinks, feels, emotions.”
Movement/Behavior	Any comment referring to the realism of movement and behavior	“The limited movements, the emotions, Okay?”
Soul/Spirit/Geist	Any comment referring to having a soul or spirit	“Of course a human is like a person who is like from the flesh and the spirits and the emotion. And the robot is only from the flesh.”; “I would say definitely a robot can never have a soul.”

What distinguishes a robot from a machine?		
No difference	Any comment stating no differences between machines and robots	"A robot is a machine, a special form of a machine."; "I always thought that a robot is a machine."
Autonomy (programmed)	Any comment referring to programmed autonomy	"What distinguishes a robot from a machine is that it has to ability to analyze situations autonomously on its own, solutions, or maybe move itself, respond to environmental input, which machine is just designed to repetitively does, do a certain job or task."
Intelligence (artificial)	Any comment referring to artificial intelligence	"For the basic thinking for me, actually, I would say the robot is a kind of, a more advanced machine that can move from place to place and it's also more intelligent for the cognition of voice and commands and these things, by vocal immediately."
Ability to interact	Any comment referring to the ability to interact with humans	"I think from my perception it would be the interaction which is easier with the robot than with the machine."
Ability to communicate	Any comment referring to the ability to communicate with humans	"We can talk and understand in a human way, because I experience a, or when I working with a machine I don't understand what is the machine thinking."; "A robot can be programmed to talk to you."
Ability to learn (machine learning)	Any comment referring to the ability of machine learning	"A robot to me is, can learn things."
Appearance	Any comment referring to general appearance	"From a machine? Erm. The look. Slightly better."
Complexity	Any comment referring to complexity	"It is the complexity behind it."
Mimicking/Resembling a human (robot)	Any comment referring to robots reassembling humans	"Looks more like a human than like a machine probably."; "I think robots imply that they are a resemblance of a human somehow."
Mobility	Any comment referring to mobility	"Actually, I would say the robot is a kind of, a more advanced machine that can move from place to place and it's also more intelligent for the cognition of voice and commands and these things, by vocal immediately."
Multitasking	Any comment referring to multitasking or multi-purpose	"Machine and robot to me, the machine is much more limited, much more special function."

3. Results

The results of the data analysis are presented as follows. First, in section III.3.1 the descriptive results with regard to the perception and evaluation of the six robots are presented in detail for each respective robot followed by a summary of the overall perception and evaluation of the robots (section III.3.2). In section III.3.3 results regarding possible explanations or causes of the uncanny valley effect are presented. Differences in the perception and evaluation of robots with regard to participants' culture, gender, profession and age are summarized in sections III.3.4 and III.3.5. Quotes from the Interviews are labeled with an abbreviation for the particular case, e.g. Ge7 stands for participant seven from the German sample, Ma5 stands for participant five from the Malayan sample and Ch7 stands for participant seven from the underage participants sample.

3.1 Perception and evaluation of robots

This section first presents the descriptive results of the perception and evaluation of the six robots separately, followed by a summary of the overall perception and evaluation of the robots. Subsequently, participants' perceptions and evaluations for the robots are condensed in order to compare the different robots and to derive answers to the proposed research questions. In sections III.3.1.1 to III.3.1.6 the descriptive results derived from the analysis of the coding process are amended by quotations from the interviews which reflect interesting aspects of participants' answers which are not reflected in the coding schema. During the course of the interviews sometimes a question was omitted or participants did not answer a question directly, but concentrated on other topics which caught their interest. These cases are missing values and referred to as "no statement".

3.1.1 Perception and evaluation of CB2

When they were presented with a picture of CB2 almost all participants (13 out of 16) reported negative feelings (positive: 1; neutral: 2) and the majority felt tense or distressed (n=11) rather than relaxed (n=2) or neutral (n=2). Negative statements were for example: "more tense. Yes, it is kind of … one identifies it as a human-like object and it looks like he needs help and this implies that one can expect a tense situation and that makes me tense, yes." (Ge1); "This one really puts me off. More than the first one. One thing, you know, erm, it doesn't really, I mean, try to like really look like a human. At least not the, this one. You see all these sort of eyebrows there (the other robots), you know? They look a little bit better. With the jaw which could be open, but this one is just like. I would say it looks like a- a doll, but it is just not suitable to be played with." (Ma5). A neutral statement is for example: "So this is science fiction. Because of the science fiction, I would say this is familiar, but …now… so in my everyday life, this would be very unfamiliar" (Ge4). Participants reported that they would also show more negative responses in the cinema when confronted with CB2 (n=7), although some participants stated that they would not care when the robot sits there (n=3) or even be interested (n=3). CB2 was perceived as unfamiliar (n=11) rather than familiar (n=4, no statement: n=1). Those who stated that CB2 is familiar referred to movies and science fiction to explain their evaluation (e.g. "I think is familiar, because of what we see in the movies of androids"; Ma5).

After the video again the majority reported having experienced negative feelings (n=10) rather than positive ones (n=2; no statement: n=4). With regard to whether participants felt safe/certain or insecure/uncertain the answers were mixed (certain/safe: n=5, uncertain/insecure: n=5; no statement: n=6). Some participants experienced uncertainty, because they could not find out the purpose of the robot. Others stated that the robot is small and has such limited capabilities that they feel safe because the likelihood of a threat is very low. Nevertheless, most participants would react negatively when they encountered CB2 in the cinema (n=10; do not care: n=3; interested: n=1; no statement: n=2). The movement was perceived as of rather high (n=9) or medium (n=5) rather than low (n=2) quality and overall exceeded most participants' expectations (n=12, below expectation: n=1, as expected: n=1, no statement: n=2). Overall, the robot was evaluated as more negative (n=6) than neutral or positive (each n=2, no statement n=6)) and rather useless (n=12) than useful (n=1; no statement: n=3). Six participants came up with some possible applications for CB2 (e.g. "In don't know what it is for? For couples without children? A Playmate for children… That is a very unpleasant thought."; Ge7) and nine participants stated that CB2 could not do anything for them in their daily life (e.g. "I think, I don't see the, to me, I always is robot is self, erm, self, self-function. But this one seems to be very baby-like, you know? So. I don't see the purpose of it. I would be thinking like: why would you like to invent something like that?"; Ma5). The majority of the participants would not like to have CB2 (n=12) and only two participants could imagine owning the robot (no statement: n=2).

There were no peculiarities in the answers with regard to participants' gender or profession; however three Malay participants explicitly mentioned that CB2 reminds them of a Malay ghost called Toyol which evokes negative associations: "One thing. In Indonesia we have this, erm, believe in ghosts and all that. So there is a ghost, you know. We call it Toyol. It is very small, looks like a boy, but hairless, bald, you know, not wearing any clothes. So that's the impression that artist always see that is over Toyol. So when I see this robot, it reminds me of this ghost" (Ma5).

3.1.2 Perception and evaluation of Geminoid HI-1

When shown a picture of Geminoid HI-1 five participants thought that they saw a human, although they had been instructed that the interview was solely about robots. Participants reported diverse emotional experiences. The majority felt negative (n=7). Some referred to the stern facial expression of the robot ("No, not so good. He looks grumpy somehow, has a tight facial expression."; Ge8) or his potential to be dangerous ("Mixed feeling. It is so human-like, is almost human. It could be dangerous (laughs). I don't know. My first impression is that he could be more dangerous than the other robots."; Ma6). Others explained that their disillusionment on discovering that it was a machine would be disturbing ("Yes. And then immediately I behave very normal, like behaving with a human, but once I realize that it's a machine this would be a quite strong shock for me. Maybe I would step back and look at it and then I start thinking… what to talk, what to say to this machine, what is it going to do. How it is programmed? Is he… many things are in my head once I realize that it is a machine. But for the first look, at the beginning, yeah, I might be very relaxed and very normal. But later on I will be not relaxed."; Ma7). Five interviewees had problems to explicitly state their feelings ("No, I have definitely no fears. But on the other side, because of his human-likeness he seems to be potentially more dangerous than the ones before. I would think that he is capable." Ge2). One participant stated that he has no feelings towards Geminoid HI-1 and two expressed positive experiences. The majority of the participants reported being tense (n=12) rather than neutral (n=1) or relaxed (n=2). Seven participants stated that they would be okay meeting Geminoid HI-1 in the cinema, because they would probably not recognize the robot (e.g. "When I don't know it is a robot then it is okay. When I, I would I think this is just another person sitting next to me. Think there is another guy, another Japanese sitting next to me. So what?"; Ma6). Five participants stated experiencing negative feelings ("Something… see the robot, I mean the artificial elements, where here becomes much more natural, the way that this thing is a robot I guess would make me a little bit uneasy." Ma4; "I would leave the place"; Ge5). Only one participant would experience positive feelings and one would react with interest (no statement: n=2). For five participants Geminoid HI-1 is familiar, mostly because of his human-like appearance. The majority of the participants, in contrast, stated that Geminoid HI-1 is more strange and unfamiliar (n=11). Two participants stated that Geminoid is unfamiliar, because they "don't know this person" or they "don't have many Asian friends". Others refer to the fact that such a human-like appearance is not normal for robots (e.g. "Because for, for robot normally you imagine it looks like a robot but this robot totally looks like human that's why it is totally strange or different from other robots. For me." Ma2). And some participants explicitly state that the unfamiliarity arises from familiarity (e.g. "I am not familiar with this robot person. But I think the human person is familiar." Ma1).

After the video a considerable number of the participants did not answer the questions, but rather asked questions themselves in order to understand the content of the video better. Some expressed being confused (e.g. "This was rather unpleasant. I missed someone commenting on what is going on. Only this robot, it makes hm hm hm, okay, and what now?" Ge6). Participants expressed feeling more negative (n=8) than positive (n=2; no statement: n=6) and both safe (n=4) and insecure (n=6). The majority stated probably experiencing negative feelings when meeting Geminoid in the cinema (n=8, do not care: n=3; no statement: n=5).

Participants evaluated the robot more negatively (n=5) rather than positively (n=1), but the majority (n=10) gave no explicit answer. Negative evaluations were often explained with the rather low (n=6) or medium (n=9, no statement: n=1) quality of Geminoid HI-1's movements which were overall below the participants' expectations (n=13, matched expectations: n=1, no statement: n=2). Answers to the questions of its usefulness were mixed (useful: n=4; useless: n=5, no statement: n=7) as were participants answers to the question of possible applications. Six participants could not imagine something or did not want to do so, but three mentioned different applications such as scaring off burglars, serving as a gate keeper or at an information desk, serving as a doppelgänger to escape from work. Four participants mentioned that he could be used as an interface to a computer to start programs, calculate statistics, etc. (e.g." I think it would be more like an extension to the computer. Because you know the computer is already there. So if you want, you want it to run some I mean (…) running on the computer whatever. I would use it for that." Ma4). The majority would not like to have Geminoid HI-1 (n=12, yes: n=3, no statement: n=1).

Germans reported more often that they would not mind encountering Geminoid HI-1 in the cinema (n=6) and only one participant stated to be negatively surprised and one would be interested. Contrarily, half of the Malayan participants reported that they would react negatively (n=4), two would not care and one would be positively surprised. With regard to the perceived familiarity of Geminoid it is remarkable that all five participants who stated that Geminoid HI-1 is familiar were Germans (unfamiliar: n=3) while the Malayan participants consistently stated that Geminoid HI-1 is unfamiliar.

3.1.3 Perception and evaluation of HRP4c

Participants were first presented with a picture of HRP-4c. When asked for their feelings the majority felt positive (n=6) or neutral (n= 3). Three participants had problems expressing their feelings, but their statements were not particularly negative ("I ... think... more interesting, a bit." Ma2; "It doesn't look frightening to me. It is not a positive feeling. Is just … I don't know." Ma5; "Astonishing, I'd say." Ge7). Only two participants experienced clearly negative feelings (no statement: n=2). One third of the participants reported being tense (n=5) and half of the participants were relaxed (n=7) or felt neutral (n=2, no statement: n=2). When asked how they would react if HRP-4c sat next to them in a cinema three participants stated that they would not mind, partly because they would probably not recognize it as a robot (e.g. "Would not be that bad. Apart from the suit it looks rather realistic. If it wears normal clothes, it would probably not attract attention in a dark cinema." Ge6). Three stated being interested (e.g. “I think I will be amazed as well and like asking for the questions.” Ma1). One participant expressed positive feelings (“I think it would be pretty nice, because I can, I can speak to it. I can explain what I feel in the movie or what I see in the movie with this kind of robot.” Ma7), but also half of the participants expressed that they would have negative experiences (n=5; “I would immediately leave the cinema”, Ma8) or even experience fear (n=2; “I would be confused. I would be scared. I don’t know.” Ma6). Participants were also ambivalent with their statements regarding familiarity (familiar: n=8; unfamiliar: n=7, no statement: n=1).

After the video, nine participants expressed positive feelings and only one negative feelings. However six participants did not answer this question directly but discussed other topics (e.g. the fact that they prefer human artists over performing robots). With regard to the cinema situation participants gave rather similar answers as those they gave after the picture (does not care: n=4; interested: n=4; negative: n=6, positive: n=1). Five participants reported feeling safe and two feeling insecure (e.g. “Not safe. I mean I know that cannot grasp me.” Ma1; no statement: n=9). When participants explicitly evaluated the robot the majority evaluated it positively (n=7) rather than negatively (n=2; no statement n=7) and useless (n=10) rather than useful (n=2; no statement n=4). The movement was evaluated as of high (n=6) or medium (n=6; no statement: n=4) quality and the rest matched the participants expectation (n=5) or exceeded them (n=6) rather than being below expectations (n=2; no statement n=3). Participants stated that HRP-4c could be used for entertainment purposes (n=5). Three participants found other applications like household chores or movement therapy and six participants could not imagine how HRP-4c could be used in everyday life. About half of the participants would like to have HRP-4c (n=7) and half would not (n=8, no statement: n=1).

In contrast to the previously reported results, there were no obvious cultural differences with regard to the perception and evaluation of HRP-4c. However, an interesting point is that some participants referred to HRP-4c’s obvious female gender which is perceived as generally more pleasant and familiar (e.g. “Yes, I think I would find a female robot more pleasant than a male robot. I am also more relaxed. It is a female robot, so it is built like a woman.” Ge4; “This is maybe because that it is a robot that depicts a woman. That is quite familiar. Does not look bad the face. Could be a cute female Japanese.” Ge6; “Erm, still weird (both laugh), but… (I: But kind of other weirdness?) Yes, not sure.... maybe because it looks like a female, because I am a male, I will be more interested to sit next to it in the cinema. If she is wearing a dress in the sense." Ma2; "The second is the dancing robot. I don't know why. It is just interesting that it can sing and dance and definitely is a female, so it is likable, because I am male." Ma2)

3.1.4 Perception and evaluation of Nexi

Participants' feelings were more mixed when seeing a picture of Nexi. Seven reported negative feelings, five neutral, two positive and one participant was not able to express his feelings in terms of negative, positive or neutral ("I feel observed.", Ge6; no statement: n=1). Also with regard to how relaxed (n=5), tense (n=6) or neutral (n=2, no statement: n=2) participants felt, the answers were quite balanced. Participants would show more negative responses in the cinema when confronted with Nexi (n=8) or even experience fear (n=2) although a number of participants stated that they would not mind if the robot sat there (n=3), be interested (n=2) or be positively surprised (n=1). Nexi was perceived both as unfamiliar (n=9) and as familiar (n=7). One participant explicitly stated that "It is difficult. It is a kind of unfamiliarity, because of familiarity, because it is more human-like, it is rather…" (Ge1). Those who stated that Nexi is familiar referred to its human-like features as well as its robotic features (e.g. "More familiar, yes. (I: Because it is more near to the…) the archetype robot features, yes." Ma4; "It is rather familiar, because at least the head is modeled after a human." Ge4).

After the video the majority reported to have experienced positive (n=8) or neutral (n=3) feelings rather than negative ones (n=4). Some participants referred to Nexi's voice which was perceived as very pleasant to explain their changed feelings: "I am surprised about the pleasant voice the robot has. I think it was very pleasant." (Ge4); "The movement was rather fluent and the voice made a difference, too." (Ge6). With regard to safety and uncertainty the answers were mixed (certain/safe: n=4, uncertain/insecure: n=7). Thus, participants answers to the cinema question were also mixed (negative: n=4; positive: n=1, do not care: n=2), but more people were interested (n=5) especially because the robot talked during the video. This ambivalent tendency in the participants' reports also holds true for the evaluation of the robot. The movement was perceived as of high (n=5), medium (n=4) or low quality (n=5) and there was no general agreement as to whether the movement was above (n=7), below (n=4) expectations or just as expected (n=5). The robot evaluated as more negative by two participants and as more positive by six participants (no statement n=8) and useful (n=8) rather than useless (n=3; no statement n=6). Fourteen participants imagined possible applications for the Nexi robot and only two participants stated that they could not imagine anything. Applications included household chores, bringing things, reading participant's emails out loud, but also working in environments with more complex tasks, e.g. “But with this communicative ability it could entertain children, talk to them. It could tell stories or do something like helping with their homework” (Ge1) or “It is not for me personally, maybe if they will have the communicating things and the touching and, that we can put her somewhere in the immigration, touching things, checking the luggage. Asking where are you going?” (Ma1). One participant mentioned companionship (Ma5). Ten participants would not like to have Nexi and six could imagine owning the robot.

A cultural influence was observable in participants’ answers of how tense or relaxed they feel when seeing a picture of Nexi. German participants tended to be more tense (n=5, relaxed: n=2, neutral: n=1) and Malayan participants tended to be more relaxed (n=4) or neutral (n=2) than tense (n=1, no statement: n=1). Moreover, after seeing the picture Germans reported more often that they would react negatively or with fear in the cinema situation (n=7; interested: n=1) compared to Malayan participants who reported less often that they would react negatively (n=3) and were rather positively surprised, interested or simply unimpressed (in total n=5). Germans also perceived Nexi as being more unfamiliar (n=6; familiar: n=2) compared to Malayans who perceived the robot as more familiar (n=6, unfamiliar: n=2).

3.1.5 Perception and evaluation of Asimo

Participants overall reported feeling positive (n=10) or neutral (n=3; no statement: n=3) and relaxed (n=13; neutral: n=2, no statement: n=1) after been presented with a picture of Asimo. Asimo was perceived as being familiar (n=13) rather than unfamiliar (n=2, no statement: n=1). Seven participants stated that Asimo is familiar because it reminds them of an astronaut (e.g. “I would categorize him as more familiar, because like I said when you already know things from this perspective and indeed he looks a little bit like an astronaut.” Ge7). Some participants had prior experiences of Asimo and either saw it on TV or YouTube or at an exhibition (e.g. “Familiar I would say because I have seen it and known it before.” Ma2). Participants seemed to be rather positive or neutral about meeting Asimo in the cinema (positive: n=4; interested: n=1, does not care: n=5) than negative (n=4, no statement: n=2).

Also, after the video, participants felt positive (n=14; no statement: n=2) and safe (n=11; uncertain/insecure: n=1; no statement: n=4). Asimo was evaluated as rather positive (n=7; no statement: n=9), rather useful (n=9; useless: n=4, no statement: n=3). Its movements were regarded as of high (n=11) or medium (n=3, no statement n=2) quality and overall matched (n=4) or exceeded participants expectations (n=9; below expectations: n=1, no statement: n=2). Ten participants mentioned a variety of other applications for Asimo besides conducting an orchestra ranging from household chores and butler services to more sophisticated jobs. Overall the expectations of the participants varied a lot. Some stated that Asimo could do more complex but repetitive tasks, which do not require higher cognitive decision making (e.g. “ Something that has a repetitive character, very repetitive, cleaning, bring letters to me, things that have to be done on a daily basis and where you don’t need to calculate risks.” Ge3) or the same tasks as humans but maybe slower (e.g. “I think he can do quite much. So, he has thumbs, normal hands. So he is modeled after the human buildup and I think that depending on technological maturity he can do everything what a human can do. More slowly I think at the beginning. I think he can be very useful.” Ge1; “Eh, because it is the movement as I told you, it is for a robot it is exceeding my expectations. It would be, it would be very nice if he can for example like being in the public places and helping citizens or maybe disabled, so or... in the hospital, helping the person to reach everything (not understandable) I think it would be nice. It is friendly, and and, it helps.” Ma1; “I would say. In general it will be more like a companion maybe, but still, still maybe to limited.” Ma2). Although participants overall reacted positively towards Asimo and evaluated it as positive and useful, only half of the participants stated that they would like to have Asimo (n=8), while the other half did not want to own it (n=7; no statement: n=1). Participants were rather consistent in their answers and did not reveal obvious differences with regard to culture, gender or profession.

3.1.6 Perception and evaluation of AR

With regard to AR, participants felt rather positive (n=6) or neutral (n=7, could not express feeling: n=1; no statement: n=2) after the picture and overall more relaxed (n=10) or neutral (n=1) than tense (n=2, no statement: n=3). People reported being more negatively surprised (n=7) or not caring (n=7; interested n=2) to see AR in the cinema. Especially the last group mentioned frequently that AR was the only robot where they imagined that it actually was in the cinema with a purpose (to clean cinema-goers litter after the movie; e.g. “Then I would think by myself that he indeed belongs to the cinema and that he has a place there, to clear away popcorn or such. Looks like a super vacuum cleaner.” Ge2; “I might wonder in the first moment, but then I might think it is a cleaning robot. Anyway, it would be unusual.” Ge4). Participants answers about familiarity were quite mixed (familiar: n=8; unfamiliar: n=7).

After the video, participants felt either positive (n=9) or neutral (n=4; no statement: n=3) and safe (n=8; insecure: n=1; no statement: n=7). When participants evaluated the robot it was perceived as positive (n=6; no statement: n=10) and useful (n=14; no statement: n=2). Movements were perceived as of medium quality (n=11, low: n=3; high: n=1; no statement:

n=1) and overall matched participants' expectations (n=14, exceeded: n=2). Overall participants' responses to the cinema questions were slightly more positive with the majority of the participants finding it normal (n=8) or positive (n=2) to have AR there to clean and there were only four negative responses. Overall participants agreed that AR is suitable for household chores (n=12) and only two mentioned additional application fields as an entertainment device with inbuilt MP3 player and as a mobile robot in hazardous environments like Fukushima. The majority would like to own AR for household chores (n=13) and only three participants would refuse to have one.

Germans perceived AR as rather unfamiliar (n=6, familiar: n=2), while Malayan participants perceived the robot as rather familiar (n=6; unfamiliar: n=1, no statement n=1) and the three participants who stated they would not like to own the robot were all German.

3.2 Overall perception and evaluation of robots and influence of movement, appearance, and context

Participants showed very diverse reactions with regard to the six different robots, both on the level of the feelings they experienced when looking at a picture or at a video of the particular robot as well as on the level of evaluating the robot in different dimensions (cf. also Table 4 for a brief summary). In the following, participants' perceptions and evaluations of each robot will be briefly summarized (section III.3.2.1) and subsequently discussed with the relevant research questions *(RQ1-RQ3)*. Section III.3.2.2 reports how and why participants ranked the robots with regard to likability especially addressing *RQ4*. And the section III.3.2.3 concentrates on where participants would regard robots as useful and in which context they would find them inappropriate, thereby addressing *RQ5*.

3.2.1 Summary of participants' perceptions and evaluations of the robots

CB2. Participants experienced consistently negative feelings and were distressed. The negative feelings were also described with fear, disgust, revulsion and sympathy or pity. The robot itself was evaluated negatively and was perceived as unfamiliar and useless. Participants' statements on their impressions included the negatively associated words premature birth, alien, "unsuitable" doll, and ghost. CB2 was the robot which elicited the most consistent negative perceptions and evaluations.

Geminoid HI-1. Similar to CB2, participants experienced negative feelings towards Geminoid HI-1. However, a considerable part of the interviewees showed themselves to be irritated and confused. They did not believe in the first instance that Geminoid HI-1 is a robot.

Realizing this fact caused negative feelings. Geminoid HI-1 was perceived as more threatening, because his human-like appearance implied more capability. The robot was evaluated negatively. The movement quality was below the participants' expectations evoked by the robot's appearance. It was perceived as rather unfamiliar and of only limited usefulness. Participants' statements included elaborations on diverse points of critique on Geminoid HI-1, ranging from disapproval of "playing God" by creating such a human-like robot to the mere confusion about why someone develops a robot just for appearance and not for functionality. Another crux for the participants was that they experienced great uncertainty when looking at the picture. Some stated being uncomfortable because they could not clearly categorize Geminoid HI-1 as human or robot. This uncertainty was partly resolved by watching the video, which revealed Geminoid HI-1's robotic nature by the low movement quality. Geminoid HI-1 thus elicited overall rather negative feelings and evaluations. However, while negative reactions toward CB2 were more spontaneous, impulsive and specific, the reactions towards Geminoid HI-1 were only partly impulsive and partly arose from participants' considerations about moral, ethical and societal implications.

HRP-4c. In contrast to the two other android robots CB2 and Geminoid HI-1, HRP-4c elicited rather positive or neutral feelings and was evaluated more positively. This was partly due to the rather good movement, the female appearance and the fact that although the robot has quite human-like body parts (head and hands) participants could easily categorize it as a robot. However, the robot was generally perceived as useless especially with regard to the entertainment context in which it was presented in the video. Some participants explicitly stated that they do not like a robot in any artistic or creative application field.

Asimo. The humanoid robot Asimo elicited consistently positive feelings and positive evaluations. Participants felt safe and relaxed. The robot was perceived as rather useful and very familiar since it reminded the majority of an astronaut. Asimo was very close to some participants' stereotype of a robot. Also some participants had seen Asimo previously in the media, which contributed to its familiarity.

AR. AR also elicited rather positive feelings. Participants evaluated the robot positively especially because of its perceived functionality and usefulness. Although some participants did not like the bulky appearance, most were okay with it, because the appearance is sufficient for the purpose. It is the only robot where participants showed a clear tendency buying one.

Nexi. Participants' answers to questions concerning Nexi were more diverse than those regarding all the other robots, where a clear tendency towards good or bad was always observable. However, participants reported mixed feelings (ranging from scared to amazed) and also evaluated Nexi very diversely (from eerie to lovely). The ability to communicate was appreciated by some participants. A frequent statement was that the robot looks unfinished and should be covered.

Addressing the question of how participants reacted towards the different robots (***RQ1***) it can be summarized that the various robots were perceived quite differently: from overall very positive (e.g. Asimo) to overall very negative (e.g. CB2). There were some robots where no general trend in the perception and evaluation was observable (e.g. Nexi) and the answers were greatly influenced by the participants' prior experiences and their initial associations. Moreover, there were some aspects of the perception or evaluation of the particular robots where participants did not generally agree and reported quite mixed answers depending on their general attitudes. For instance some participants found the thought of any robot in a cinema generally disturbing, regardless of how the robot looked, while others reported sometimes feeling okay with it and sometimes not, depending on whether they liked the robot or not. Some participants on the whole did not want to own a robot, because they regarded this as not being useful while others stated that they could imagine having a robot just because it might be interesting, or to show off to visitors.

Depending on the robot, participants sometimes mentioned fears or anxieties ***(RQ2)***. Some robots were perceived as scary (CB2; Geminoid HI-1, Nexi) although the reasons for this perception differed. Regarding CB2 and Nexi it was clearly the appearance that put participants off. However, participants did not explicitly state that Geminoid HI-1 looks scary, but it rather scared them because they were not able to tell whether it is a human or a robot from just seeing the picture. Participants felt uncomfortable at the thought of a society where robots would live among humans unrecognized.

With regard to how the aspect of movement influenced the perception and evaluation of the robots ***(RQ3)*** it could be observed that participants generated expectations about the robots movements when seeing a picture. Expectations were greater when the robots were more human-like. Some participants were surprised when the observed movement exceeded their expectations. High quality in movement was generally perceived positively and as a technological accomplishment. For instance, although CB2 was generally evaluated negatively, its actions were perceived as very lifelike and this was mentioned as a special characteristic of the robot. Limited movement was either seen as appropriate for less human-like robots (AR) or as disappointing. However, although participants were disappointed by, for instance, Geminoid HI-1's limited movements, they also felt less uncertain and insecure, because the movement provided the needed cue to clearly categorize Geminoid HI-1 as a robot (e.g. "I felt it would move much better than…to move more softly and like a human because it looks like a completely a human, but the movement reflect the way of design. It reflects that it is a pure robot but has the skin of a, skin after human." Ma7; "Actually when you showed this to me I did not think it was a robot. Now I know that it is." Ma5).

Table 4: Summary of the overall perception and evaluation of robots

	CB2	Geminoid HI-1	HRP4c	Asimo	AR	Nexi
Feelings	Negative, distressed, after video still negative feelings	Initial disbelief; negative feelings or problems with explaining feelings, distressed	Positive/ neutral; rather relaxed, after video positive	Positive, relaxed	Positive/ neutral; relaxed; after video also rather positive	Mixed feelings; mixed with regard to tense/relaxed, after video more positive feelings
Feelings /keywords	Fear, disgust and feelings of pity, repulsion	Disbelief, fear, threatening	Interest, astonishing, positive,	Positive, excited, relaxed	Positive, relaxed, amused	Scary, eerie, sympathy/ pity, unpleasant, versus: cute, lovely, nice
Cinema	Negative responses	Mixed responses: negative, or people think they would not notice	Mixed responses	Mixed responses, rather positive	Mixed responses: negative or do not care	Mixed responses
Safety/ uncertainty	Mixed responses	Mixed responses	Rather safe	Safe	Safe	Mixed responses
Evaluations	Negative, movement of rather high quality	Negative or no evaluation, movement of low quality	Positive, movement of rather high quality	Positive, movement of high quality	Positive, movement of medium quality	Mixed responses, movement mixed responses
familiar	Unfamiliar	Rather unfamiliar	Mixed responses	Familiar	Mixed responses	Mixed responses
usefulness	Useless	Mixed responses	Useless	Rather useful	Useful	Rather useful
Own the robot	No	No	Mixed responses	Mixed responses	Yes	Mixed, rather yes
Impressions / Key words	Impressions included: alien, doll, ghost, looks as if switched off, premature birth	Alarming, threatening,	Female, nice appearance, technological achievement versus: not interesting, not useful	Astronaut, complete, robot stereotype, friendly, likable	Housemaid, usefulness is appreciated; easy to categorize, vacuum cleaner	R2D2, robot stereotype, piece of art, versus: unfinished/ uncovered, something from an anatomy book, alien-like big eyes

3.2.2 Ranking of robots & reasons

In order to examine more specifically which physical characteristics and which abilities are associated positively and which are associated negatively *(RQ4)* participants were instructed to order the robots with regard to their likability and elaborate on their ranking by explaining their reasons and comparing the robots. Participants were then asked how important different body parts or aspects of appearance were for their likability ranking. The influence of context was also discussed *(RQ5)*.

First, participants ordered the robots with regard to their likability. Overall the ordering shows that Asimo and AR were placed predominantly in the first ranks with regard to likability, while CB2 and Geminoid HI-1 predominantly in the lower ranks. HRP-4c and Nexi were placed in the middle ranks (cf. Table 5).

Table 5: frequency of robots ranks on likability order (ordered alphabetically)

Rank 1	Rank 2	Rank 3	Rank 4	Rank 5	Rank 6
AR	AR	AR	AR	AR	CB2
AR	AR	AR	Asimo	CB2	CB2
AR	AR	AR	Asimo	CB2	CB2
AR	AR	AR	CB2	CB2	CB2
AR	Asimo	AR	CB2	CB2	CB2
Asimo	Asimo	Geminoid HI-1	Geminoid HI-1	CB2	CB2
Asimo	Asimo	HRP-4c	Geminoid HI-1	Geminoid HI-1	CB2
Asimo	Asimo	HRP-4c	Geminoid HI-1	Geminoid HI-1	CB2
Asimo	Asimo	HRP-4c	Geminoid HI-1	Geminoid HI-1	CB2
Asimo	Asimo	HRP-4c	HRP-4c	Geminoid HI-1	Geminoid HI-1
Asimo	Geminoid HI-1	Nexi	HRP-4c	HRP-4c	Geminoid HI-1
Asimo	HRP-4c	Nexi	HRP-4c	HRP-4c	Geminoid HI-1
Asimo	HRP-4c	Nexi	HRP-4c	Nexi	Geminoid HI-1
HRP-4c	HRP-4c	Nexi	Nexi	Nexi	Geminoid HI-1
HRP-4c	Nexi	Nexi	Nexi	Nexi	Geminoid HI-1
Nexi	Nexi	Nexi	Nexi	Nexi	HRP-4c

AR. Participants were asked to elaborate on their reasons for the proposed order of the robots. Reasons for a high rank for AR included that it is useful in everyday life and that its purpose and functionality are obvious (e.g. “It is the epitome of functionality”; “The maid, is very useful, I’d say. Very practical, that it can help me with stuff, like cleaning and those tasks” Ma2). Some people liked the more abstract appearance with not too many human-like features, making the robot familiar and easily categorizable as a robot (e.g. “same level of abstractness (as Asimo)” Ge6; “This (Geminoid HI-1) is more like human being, and this

(AR) is definitely a robot." Ma3; "Housemaid is obvious" Ma5; "This one is a pure machine. Is more useful in daily task. You see. But once you have it, you will have always the feeling that it's only a machine, nothing more." Ma7). Reasons for lower ranks were its bulky appearance ("This is one of the last ones, because he is most square-cut, that is like a machine I don't want to come near." Ge4; "This one is okay, just now but, I think the, the look could be improved." Ma6).

Asimo. With regard to Asimo, reasons for higher ranks for likability referred to its perceived potential ("has the greatest potential, you can teach him everything because he has a human-like look and joints" Ge1; "Because I think there is more to it than what we have seen. So I am, I don't know. Because when I heard about it, I liked it. So I was very curious about it." Ma5). Moreover participants liked the robot's appearance which reminds some participants of Star Wars and other movies involving robots and thus corresponds to participants stereotype of a robot and thereby is familiar ("It's abstract enough to not overstress the feeling of human-likeness." Ge6; "I guess because it is the familiarity, okay? Also this is *the* robot. Something like this, and it is familiar, something familiar, it is a familiar picture. And the movement you know, you know is very fine." Ma6). Consequently, Asimo is easily categorizable as a robot (e.g. "It reminds you all the time: this is a robot. But I think I can live with it." Ma3; "Fits what I perceive robots to be." Ma4). Particularly Asimo's movements were regarded as positive (e.g. "Appealing good arm movement." Ge4; "This one almost the same with less benefit from that. I mean, if I am going to buy one, I buy this more than this. I don't care about that. But the movement of this one is softer like, more like human." Ma7)

HRP-4c. Participants criticized that HRP-4c seems to be quite useless. Although participants liked the fact that the robot had an obvious task, they did not appreciate a robot for entertainment purposes. Two found this explicitly annoying and unpleasant. However, overall its appearance was seen as a positive surprise. Participants liked the mixture of robotic and human-like elements and the robot's movement (e.g. "HRP-4c and Asimo more or less quite the same, but this one has a better appearance. So if you give her, give some clothes, then she can pass on as another, you know? Another person in the house." Ma3; "This one because the way it moves and the face, the way it sang, it looks more like human. So you feel that it is a nice thing to see, even though it maybe is not useful that much in daily life task, but at least you feel that there, it can do something and it is nice. You can listen to this." Ma7). One participant referred to its obvious female gender as being pleasant (e.g. "It is just interesting that it can sing and dance and definitely is a female, so it is likable, cause I am male." Ma2).

Nexi. Comments about Nexi were rather mixed. Some participants liked its appearance while others did not ("Just looking nice" Ge2; "Likable, perhaps because of big eyes and pleasant voice" Ge4; "I mean in a sense it looks very bad." Ma2; "This one as I was saying, because of the look just now it could be dangerous and erm. Ja it is just part of the face and you can see all …whatever…I don't know. Yes the cords. It looks dangerous. Because I have small children in the house." Ma6; "This one is...is a physical feature. I told you, is like a naked robot." Ma3; "Something in between, compromise between robot design and human-likeness." Ge6; "This one it has a more human feature than the normal robot, but less than this definitely. You see. So yes you had the feeling that this is a robot, but still it can, it can give you gestures, it can give you some kind of face movement. Regard the usefulness, in daily task I don't think it is very useful. Maybe for simple task only, like cleaning house or something. But you would love to sit with it and talk, you see?" Ma7). Nexi's positive aspects were those mentioned in the video: that it is able to speak and its communicativeness, which elicits interest in the participants and that it can bring things and is mobile (e.g. "communicativeness is positive, makes the robot interesting." Ge1; "I am impressed by the capabilities although it still causes a negative feeling." Ge7). Also, with regard to its purpose and usefulness, participants gave mixed answers ("It is useful, can bring things." Ge8; "I really don't understand what's the purpose? Yes. Also it seems like it is not finished, hm?" Ma1;"This robot is able to do a lot of things. I would see. Is able to talk, able to move its arms things like that, but maybe it is not so likable, because it does not look attractive enough. I mean in a sense it looks very bad." Ma2; "And this one because of the, I think, the movements. Because it is harden surface it doesn't look very natural, but I think there is, it can actually function more than. I was pointing to the face, because, you know, I was thinking about companionship." Ma5).

CB2. Comments regarding CB2 were predominantly negative. Participants justified the low ranks in likability with CB2's appearance (e.g. "looks like an alien, irritating" Ge6; "Weird robot. I think his face looks scary" Ma2; "Bio Child: And these two. I don't like this particular one. It looks a bit retarded. Yes. So I would pity. I would not like to be around it." Ma5) and the lack of usefulness (e.g. "This does not look nice, not very useful." Ge8; "This one and this one I see that they are. They are just a kind of science fiction to make it more close to human, but without any benefit. Without any usefulness at all, you see? Is just to see how the human can reach in science." Ma7). Furthermore, some participants were rather repulsed without stating reasons for their reactions (e.g. "just unpleasant" Ge7; "This one because of my perception, because I didn't want." Ma3; "These are the two which give you a bad feeling." Ma6; "This surprises me with its movement, but also a little bit uneasy there?" Ma4).

Geminoid HI-1. The few participants ranking Geminoid HI-1 at higher levels of likability were somehow in two minds about the robot (e.g. "I forgot about him actually after I saw him the first time on TV. But again he surprised me somehow and he is cool in a kinky, wacky way" Ge2; "Because it is fascinating how human-like a robot can look like." Ge4), but overall participants did not like the robots human-like appearance (e.g. "I do not like the appearance." Ge8; "First glance, you know, he looks fine. First he looks like a human. But the more when you see how he moves is like you, you. I wouldn't want to trust this robot doing the house chores." Ma3; "It looks scary." Ma5; "The movements need more work, looks grumpy, not so likable." Ge6). Also, like CB2 Geminoid HI-1 was not regarded as useful (e.g. "This one and this one I see that they are. They are just a kind of science fiction to make it more close to human, but without any benefit. Without any usefulness at all. You see? Is just to see how the human can reach in science Geminoid." Ma7; "I don't see what is its purpose." Ma2).

Meet a robot. Participants were asked if they had the chance to meet one of these robots, which one they would like to meet. Most participants wanted to meet Asimo (n=6) and Nexi (n=5), because Asimo was their favorite robot and Nexi seemed to be most interesting, because it talked in the video. Three participants wanted to meet HRP-4c. One wanted to meet AR and one Geminoid HI-1, because the participant was curious about the robot although he did not like it very much.

Importance of body parts & appearance. Participants were also asked how important different parts of the robots' bodies or characteristics were with regard to their likability ***(RQ4)***. The answers were very diverse. Several participants did not mention specific body parts, but rather referred to the overall impression of the robot, the overall shape and regarded the functionality as important ("Body parts are not important for deciding on likability." Ge2; "No, just the overall appearance and how I liked it was important." Ge8; "For me? Body parts in terms of human-like? I don't see necessity for that. I think more of function." Ma5; "I think that the shape of the body should match the purpose, the functionality. For instance this one (AR) is not really nice, because the looks like bulky, but it is suitable for the purpose." Ma1; "I don't know but usually my first preference is based on the functionality." Ma1; "I like more round shapes. It could also be rather smooth, so it should not be wrinkled. Smooth shapes are important to me." Ge4). Referring to CB2 and Geminoid-HI-1 participants stated that the appearance gives an overall negative impression. Interestingly, CB2 and Geminoid

HI-1 are perceived as rather useless, although at least Geminoid HI-1 could be assumed to have the potential to do the same things as humans. However, the video obviously revealed its limitations, and the resemblance of human appearance without a connected functionality is evaluated negatively (e.g. "Yes, it (appearance) affects my likability to the robot. Like this one because I think it is really… it is a robot but it is near to the human in terms of structure. And this like because of face and gesture. This one it's very clear to me that it is just a machine. (I: But the usefulness is higher.) Exactly. Regarding this one even if it looks like a human and the movement is soft in the video, but the idea is, I don't see any usefulness to use it for a human. This and this (CB2 & Geminoid HI-1), they look like a human yes, very close and this is what is distressing me more provided that I don't see any, any kind of task can be given to them or they can't do, at all." Ma7; "Geminoid's appearance is impressive, but since he has no abilities, it's all fake." Ge1; CB2: "I don't like the appearance…makes…it's so babyish and so needy…" Ge1).

Some participants mentioned specific body parts like the:

- **face** (e.g. "The face is important. Here you can't see it, but I would imagine it (Asimo). The face should be friendly or at least human-like and should smile." Ge4),
- **eyes** (e.g. "Eyes are important, but nobody had expressive eyes (all had dead eyes), and facial expressions." Ge5),
- **arms and legs** (e.g. "For me I think definitely the arms and the legs are very important for the robot to be, to be in a sense useful or were interesting robot that are able to move by its own, yes. But it does not really need legs I would say. Wheels are okay. Yes, but now to think of it: wheels are not so flexible, that you cannot climb stairs. So in the end, legs are the best I would say." Ma2);
- **hands** (e.g. "I think that normal hands, human-like hands are good. But mechanical hands are okay for more mechanical robots (points to AR). Certain characteristics of appearance have to match the overall impression." Ge6; "And hands definitely. That it can be able to use its hands to grab things, maybe shake your hand, things like that. It contributes to the usability, the usefulness of the robot, and the more useful it is, it's more likable for me." Ma2),
- **voice** (e.g. "The voice should be pleasant. It should be a female voice." Ge4)

Moreover, two other aspects seemed to be of importance. First, *familiarity* was a key characteristic. Participants mentioned that robots corresponding to their stereotype of robots were also more likable (e.g. "This (Asimo) reminded me of a toy and of Star Wars and thus for me it is the classic robot, like I would imagine robots." Ge4; "What is unfamiliar is perceived as unpleasant." Ge7). As robots conforming to stereotype participants mentioned Asimo, AR and sometimes Nexi. Second, again the quality of *movement* was important ***(RQ3)***. Higher quality in terms of smoothness and adequate velocity was evaluated more positively (e.g. "Human appearance is important. If you try to imitate so much, but you still don't manage it, so I would rather have like this (Asimo). The more you are worrying that this is just a robot and somehow. But the way it is moving is just one. I think I see these two (Asimo & HRP-4c) as good, because they are moving better. I suppose. How the Robot moves around also plays an important role in my choice. So you want to see it moving smoothly, you know is like, when you, you see that this robot is doing some chores at home is like, know? So is like: when is it going to finish? It comes into your mind. You get distracted, and also you get. You can't wait for it to be done. Yes, so I want a very smooth moving robot." Ma3; "Movement is most important and having it look like, you know? Quite similar to our human, of course, don't see like a kid. But I see the movement is much better." Ma3; "This is, yes, the movement of all the fingers and I think that is important. Like the one, this one this you know? Yes. It will ease the movement you know…" Ma6; "As you can see the small human-like are not that necessary. To me if it is not human-like body parts perhaps it would attract me more, you know. Because I still see things: this is machine. The body parts must tell with its mobility. Fluidity of gestures and stuff like that I think." Ma4). Furthermore, participants also reported that the robots' height influences their perception. For instance, one participant who initially was afraid of Nexi's capabilities was relieved to see that Nexi is rather small and thus evaluated the robot as less threatening.

In conclusion, some distinct aspects of appearance have been mentioned as being important (e.g. face, eyes, hands, voice). However, there was no general agreement among all participants as to whether a robot should feature these aspects of appearance ***(RQ4)***. CB2 and Nexi both feature aspects of the baby-scheme with a large head and big eyes compared to a small body. Participants acknowledged this, but were indecisive about whether they liked it. While some participants liked facial features, others preferred Asimo or AR both of which disguise facial features. The general agreement is that every aspect of appearance of the robot should serve a specific purpose and that the mere resemblance of human appearance without a connected functionality was evaluated negatively.

With regard to the influence of context ***(RQ5)***, it could be observed that participants referred to the different contexts in the videos to justify their evaluations. For instance Asimo was in general likable and perceived as pleasant and potentially useful, but the specific context of Asimo as the conductor of an orchestra was perceived as negative by those participants who regarded art, music and performance as areas which are exclusively for humans. Doing household chores was a context which was mentioned very frequently by most participants as a suitable place for robots and some took this as the typical context for discussing the positive and negative aspects to include the other robots, not just AR. It seems that a minority of the participants had problems in imagining the presented robots in contexts other than those presented in the videos.

3.2.3 Possible and impossible application fields

Also with regard to the influence of the context on participants' perceptions and evaluations of the robots ***(RQ5)***, participants were asked to imagine possible and impossible application fields, i.e. application fields in which they would like to see robots and those where they would find robots as inappropriate, disturbing or annoying.

Possible application fields. Participants were asked to think about possible application areas for robots. Some participants had obviously no imagination regarding what robots could be useful for, others frequently stated that robots should be used for the classic *dangerous-dirty-dull* tasks:

- "Well, I think inefficiently you still continue to get robots to do task like this, but also more the dangerous stuff. Trying to get into buildings, get into closed spaces, dangerous spaces. I mean to environmental management. So I would assume there is more robots use to look into disasters, yeah, those kind of things" Ma4,
- „I hope that in the (not so far) future every work/task a human does not want to do can be overtaken by a robot, e.g. cleaning sewage water systems etc. I don't see a point in burdening or even forcing humans to do something like that when technology can handle this. There are theories that high culture could only develop because the slave caste released the philosopher caste from work, so they could work on this high culture – So I hope for a high cultural impact." Ge2,
- "Everything that is repetitive, or where you have to move heavy things." Ge3,
- "Robots are suitable for tasks humans do not like to do or which are unpleasant. For every task that is monotone, repetitive, and physically challenging robots are a good alternative." Ge4,
- "Household chores. Tasks that people do not like to do like working on production lines. Replace people there, so that they can do nicer jobs." Ge7,

- "Household chores, crafting, physically heavy work, welding. Everything that humans are not good at or where it is too dangerous." Ge6,
- "Of course there are many… medical … a lot… surgery- right? yes, for surgery." Ma6.

The use of robots for household chores was an especially popular topic in the interviews, probably inspired by the AR video (e.g. "Household tasks and for instance receptionist." Ma2; "Doing household. For example: cleaning the house. Vacuuming, mopping, all that, washing the cars, of course cleaning the bathroom..." Ma3; "Housemaid" ma4; "Cleaning floors, you see? Household, exactly. And also … entertainment. Receptionist, it could be." Ma7.

Participants also discussed application fields which depended on the robots' capabilities. Therefore, communicative robots or human-like robots are considered to be capable of more tasks than non-communicative robots or non-human-like robots, respectively (e.g. "Application fields depend on robot capabilities. For some tasks it could be better that they look human-like: e.g. as concierge or toll station. If it is about simple tasks, they could do them. But for everyday tasks, for instance the cleaning robot, appearance does not play a role for me, because there only the function is relevant." Ge1; "Like for instance, this one? At first I don't really understand but then they talk to each other so they can communicate very well and then there is like the singing and dancing this is like beyond my expectation. And then this one also can move and touch things." Ma1; "Yes, (laughs), she said she do the social interaction, right?" Ma1). One participant saw Geminoid HI-1 in a military context (e.g. "Defense. Yes, the scary one (Geminoid). This looks so to me." Ma5).

Some participants discussed the question of whether humans should only be replaced in jobs, when this would simultaneously offer them a better one ("But on the other side you have – in our society in which everybody has to work to earn money – you have quite the problem that all the workplaces would be omitted. But if we could handle this differently, then I think: awesome, robots can do that." Ge4)

Impossible Application fields. Participants were also asked to think of application areas where they would find the deployment of robots inappropriate or annoying. If they did not come up with application fields themselves they were asked to think about their opinion about a robot as teacher, babysitter, dog-sitter/dog-walker and nurse.

One participant explicitly stated that she does not want to have robots at all ("Okay, going to market? No. Or doing my work, helping me: no I don't think I want that." Ma3). Another participant was skeptical ("I would not like to have them anywhere, not for children, not for adults." Ge5), but subsequently stated that "supporting actions for a human could be okay". Participants widely agreed that robots should only serve as assistance to a human who is in control:

- "A teacher? Along with some human teacher. Next to the human teacher yeah. But alone: no." Ma7,
- "A nurse, to an assistive extent. Not for touching, feelings, but perhaps, you know, taking care, making sure that everything this equipment is running smoothly. So is like a robot at hand. Just checking. For else we have a real person." Ma3,
- "Yes, they can. But when humans are around. With a nurse aside." Ma5.

However, participants discussed the question of whether robots acting autonomously are either inappropriate or just unlikely. The fields they would be working in are highly complex, rapidly changing and thus hardly predictable. Therefore, deploying robots would put people at risk of being hurt in some way. This includes physical, but also socio-emotional damage. Social long-term interactions require particularly unique human-like abilities which robots are considered not to have. Thus they are regarded as inappropriate and potentially harmful:

- "Teacher, imparting knowledge on higher levels... maybe it is possible to have them as tutors/private lessons, so easy things. But interpretative things and cultural things will be hard – I cannot imagine this. But beside – a dummy for everything, raising children or telling stories for children. Babysitter no – because children are breakable and if there is a malfunction. So rather not, but this is a technical fear not a moral fear." Ge1,
- "Teacher... hm... I would say: no! Because. Because, I am not sharing. If the robot is able to recognize human responses like what are the class feelings, what are the students expressing, or feeling or the kind of emotion the class has, then it might be suitable. But I cannot imagine- how can a robot be able to recognize this kind of input, human-human interaction in a sense." Ma2,
- "A robot would not know what is happening if a child falls down the stairs and gets hurt. I cannot imagine that he knows." Ge6,
- "Also when it comes to, for examples, which involves more, -- for example like the teaching and learning? It needs more connection, like human connection. I think like teachers you can train but be a teacher educator it's a different thing, and also when you. - It's like the caring for example it's like caring elder persons or the sick persons it needs the more emotional part --?" Ma1,

- “Caretaker for a child. Definitely I would say is not okay. Cause, I’ve never had a child, but taking care of a child is definitely the most hardest thing you can do, is a lot of things you need to take care of, you need to be constantly aware of things. And that’s only part of the area. Another part is, I do believe that children, or child, or babies need human interaction and the robot can never provide like do voices of the parents, the singing maybe, the touches -- things like that which can never be replaced by a robot. Caretaker for pets. Well, it seems Okay. If a robot would take care of a pet. to me it seems okay, a pet. To a human definitely not.” Ma2,
- “Not appropriate, because children are unpredictable. And this thing are all programmed. So if something would happen which is not programmed. You may hurt the children. You may put the children in danger.” Ma3,
- “I would be a bit fearful. Because, I think, because… I keep thinking that their abilities is limited therefore they lack emotion so I think it might be inappropriate. Yes. It has to be supervised.” Ma5,
- “No take care for children, like a babysitter. No. Absolutely not. A second point as well like taking care of elders, you see, also not. Of-in hospitals…more than mopping and cleaning the floors: no. Actually, still we are humans and they are robots. Whatsoever- especially for the children and elders. They need sensation, some kind of feelings. So to put them around with robots, you are killing the humanity in them. Since childhood and for elders that they don’t feel that they are dealing with a person, even though it is talking, but they would feel that it’s not a human. So I think it would give a negative impact on them later on. Even though it can serve them for the time being for something. Maybe giving them the food, or cleaning for them or even talking, giving some noise, but it’s not enough for them. Actually, this is why I don’t think that robots can be useful in this at all. At all. Like also for dumb people, for blind people to guide them as example, also robots are not appropriate. “ Ma7,
- "Social interactions are okay unless they need emotional bonding. So short-term social interactions are okay.” Ma1,
- “I have doubts that robots (in the near and far future) can do certain things that are human specific like giving physical closeness or human sympathy [..] not because of ethical concerns, I just doubt that they will be able to do this. You would need a feeling robot – and that is so SciFi!” ge2
- “Everything interpersonal. At a counter I would prefer a person with whom I can communicate. Babysitter? Everything where you might have to improvise is

inadequate. Also not supporting a nurse. This is about interpersonal relationships. It is not just giving someone a dinner tray." Ge3.

As another unsuitable application area the military was mentioned by two participants:

- "I would be worrying when they would be in defense actually." Ma5,
- "Military. Shouldn't be in military." Ma4.

Finally, participants would not like to see robots in areas where humans achieve extraordinary accomplishments like sports and entertainment:

- "Robots should not be artists. They cannot replace artists." Ge6,
- "The thing that comes into my mind is robot as entertainer. That what the dancing robot do, the singing robot do. I think robot can never replace a human entertainers in a sense that they can never really sing, the can never really dance. That's one of the few things I think robot can ever be useful or replace the human." Ma2,
- "Sports. Yes. Then it will be no longer, erm, you know, sports. You know if you get humanoid, android in sports than it is no longer a human endeavor." Ma4,
- "Director of an orchestra? Not as an orchestra, there are no present. I mean they have a specific movement, but the Maestro follows feel which a robot, well I don't believe that will get this feelings, so it cannot feel the music." Ma4,
- "Definitely not entertainment. If I say entertainment that is, if you watch this one, in a sense it is okay. But in terms of stage performance: no. I wouldn't want to see a robot. I don't come to see a robot sing. I want to see a human dancing." Ma6.

In conclusion, it seems that some participants were influenced in their answers by the context in the previously presented videos. Thus, for instance, the context of robot in the house was a popular topic in the interviews. In which contexts the robots were presented sometimes influenced participants' evaluations of the robots in terms of usefulness. Apart from this, participants widely agreed that robots should be used for *dangerous-dirty-dull* tasks in order to free humans from dangerous or unpleasant work. However, robots are also accepted as a demonstration of technological achievement.

3.3 Results regarding causes/explanations of the uncanny valley phenomenon

Participants were asked a series of questions intended to explore causes or explanations of the uncanny valley phenomenon ***(RQ6 & RQ7)***. Two questions dealt with the fear of being replaced (MacDorman, 2005; MacDorman & Ishiguro, 2006, section II.3.3.1) and two questions dealt with the question of whether robots are at category boundaries and thereby eliciting states of uncertainty (Ramey 2005, Ramey, 2006; section II.3.3.2).

3.3.1 Fear of being replaced

After the question about possible and impossible application fields the interviewer asked the interviewee: "How would you feel, if I say that now I am a robot? Imagine I am a robot, how do you feel about this?"

Most participants stated that they simply would not believe that the interviewer is a robot (n=10; e.g. "I would not take you serious." Ge1; "I do not believe, because you are definitely human, how you laugh, and you have humor." Ge4; "My inner rock-solid believe is that we will not achieve it [to rebuild a human]." Ge5; "Would never believe that (both laugh). Yes. I could never imagine or it would be totally unbelievable for me that you told me that YOU are a robot." Ma2). While the German participants were all very straight forward in their answer (all of them mentioned to not believe this), some of the Malayan participants reacted with positive and negative surprise (e.g. "would be surprised, but it would be okay." Ma4; "I will be very, very surprised? Have we, you know, gone so advanced? That I am talking, conversation, communicating with a robot? Very surprise, and then very surprise and then Okay. I don't mind talking to a robot. I am just communicating to another human being. But surprise in a good way. Surprise that technology has been so advanced without me knowing." Ma3; "Wha? Surprise! Okay, positive in a sense that the kind of things you can do. But negative in the sense that what are you, what are you, you know? What are you doing? (I: So that would cause you to feel unsecure?) Yes, insecure." Ma5). These participants mentioned that they would feel like wasting their time (e.g. "I won't believe (laughs). I won't believe. It will be, it will be… If it's the truth. If I discover that you are a true robot. I just leave. Because I feel I waste my time with something that doesn't feel, feel me or doesn't know what I am talking about, is just recording something. You see. I am sorry, but it would be difficult to accept that I spend half an hour talking and discussing, I am thinking that I am with a human, but I end up that you: no. I am with a robot." Ma7) or were confused and scared about this possibility (e.g. "Ah no! (laughs). How would I feel? (laughs) Oh. I feel so scared. No! Are you? (laughs), Ah no! You robot. Oh. Well you could be. No you're not a robot. You're not a robot, but you could be a clone. But not a robot, because it is too perfect. No. A clone, yes." Ma6)

Subsequently, participants were asked whether they would like to have a *robotic doppelgänger* of themselves. The answers were very mixed. Six participants said yes and ten said no, two of them without further explanation.

Some participants disliked the idea, because they wanted to be unique and did not like the thought of sharing their identity with someone (e.g. "Robot like me. No. I don't want. Because I have been created me. I had been created as me. And I am the only one like this. So why to accept someone to look like me?" Ma7; "I don't want to share my identity with someone. […] You never know what the robot is doing on behalf of you." Ge6; "I wouldn't want that. Never. No because I feel that there should be only me. So I don't want this another robot who is just like me, Okay? So especially when it comes to, you know, in the family and all that. I wouldn't want the love, the attention. It's like, you know, somehow you are making your family: Ey, there are two of you. I feel that they are going to divide the love. You know? Unless will have another robot like you. Who is just an image of myself exactly. I wouldn't want that." Ma3; "I don't. A robot double me? In the Malay society, okay. There is a ghost that can be your double. You don't want that. I think that is that. Well there is believes of that. There are stories, believes. You going out somewhere. A double will come, take over your house, your family. That is not a relaxed feeling. Something taken over you." Ma4).

Others disliked the idea, because they did not regard it as useful to have a robotic doppelgänger („Hard to imagine in which situations I would use that. There are hardly things I would hand over. I would be afraid, I think. When I would see myself double and nobody can guarantee for the safety that he does not take over my identity completely later on. I don't know how intelligent they can be, when they don't only work on algorithms, but can show feelings and hear sounds and learn from humans – that would make me anxious." Ge7; „I don't like to let other people do things, I prefer doing them myself." Ge8; "If I made a double-me like in the form I think it's, the first that comes into my mind is what is it for? […] Yes, because I see myself, a person is like a mix of both physical and emotional, is like more mix. (I: So there would be something missing in the robot?) Sure! (both laugh) Yes, it's like the emotional and the spiritual part would be missing." Ma1; "No! I guess I am very influenced by movies. I don't see the purpose for it. I you know sometimes they. I think there was a movie where they actually have this doppelgängers actually functioning for them and they are not mobile. I don't see this for me. I like the way we are mobile doing things." Ma5).

Four Participants stated that it would be okay to have a robotic doppelgänger as long as they have control over it (e.g. "Okay, if I have control over the robot." Ge1; "If it is just a double ganger, then yes. I would say, I would be interested. A robotic me. But I would not wish that it can act independently. If it can mimic me it'll be okay. But if it does actions that is out of my control maybe out of how would I act maybe I would be more resistant to the idea." Ma2; "That is an interesting idea. I would like to have one, but I don't think is possible. To do the household chores, yes. But not if in the bedroom. (laughs) Oh oh, I am so sorry, Oh my god. Household chores yes, I would like to have something to do exactly what I can do in the house." Ma6).

Two participants had no concerns and would like to have one ("Yes, to make funny movies." Ge3; "That would be awesome when it would be a really good one." Ge4).

As already concluded in the previous sections, some participants were sensitive to the question of robots living among humans unrecognized. Moreover, some, but not all, participants expressed unpleasantness at the thought of sharing the attention and love of others with a robotic doppelgänger. Others were content with a robotic doppelgänger as long as they were in control of the robot. However, the majority of the participants regarded a robotic doppelgänger as still being in the realm of science fiction rather than a real possibility, leaving their statements hypothetic, which was also reflected in their disbelieving reactions with regard to the question of how they would feel if the interviewer were a robot.

3.3.2 Categorical perception of robots and humans

Ramey (2005, 2006) suggested that (very human-like) robots elicit uncertainty of whether to categorize them as humans or machines. Thus participants were requested to describe their robot stereotype and at the end of the interview they were asked to think about humans, robots and machines and what the differentiating characteristics are.

Robot stereotype. When asked to describe their robot stereotype, ten participants described some sort of humanoid robot (e.g. "So, for sure robots are humanoid, they have legs and arms. They have a metal surface and a square shaped head, yes. Robots are humanoid. They are a mixture of human and machine characteristics." Ge1; "I can just imagine robots from movies which indeed have a very human-like figure and which can do what humans do – movement and posture and such." Ge3; "C3PO, Star Wars. I first think of this when I hear robot. So a more intelligent type, not only those assembling cars, that is only on the second thought. Or iRobot or so. So robots that can do a little more than just fix a screw." Ge6; "A little like iRobot, silver, moves somehow, mechanical. (I: like in the movie with arms and legs?) Yes, so quite a bit human-like." Ge8; "It is like a -- human -- in a machine form." Ma1; "Yes, they call it Gundam, Japanese robot (like Transformers without shape shifting).” Ma2; “But what comes into my head the first is a little human machine moving-- with hands and legs, but moving in a proper way like a human.” Ma7). Participants referred a lot to examples known from movies like Sonny from the movie iRobot, C3PO from Star Wars or Gundam and Transformers. One participant referred to R2D2 (“You are asking me to visualize what I see would be something like R2D2 like in the movie you know in the movie what was it, the movie Star Wars was it”; Ma3) and one mentioned the classic industrial robot arm. Two described technical features (e.g. “My archetype… I imagine it to be of metal and plastic and it has wires and pipes and circuit boards, so a bit like a computer. And depending on what it shall do it has grapplers. And then it has sensors…” Ge4). Lastly, two participants had more diverse pictures of robots (e.g. “Quite a few pictures. The star wars, the iRobot and also the Japanese. I must think of the you know? The robotic, you know, house helper which can be quite flat and so one. (I: Roomba?) Yeah.” Ma5; “Well it ranges. I have seen a recorder robot, or a music CD robot that can dance to the rhythm of the music. To erm, like you said humanoids, to robots in the movies, yeah.” Ma4). Accordingly, participants described their stereotypes as very human-like (n=8) or at least little human-like (n=5) rather than not at all human-like (n=3).

Robot versus human. Participants were asked to elaborate on the characteristics that distinguish a robot from a human being. Participants mentioned characteristics regarding the physical nature and life-cycle of humans such as *creation/birth* (n=1), *material (flesh;* n=1), *metabolism* (n=1), and *mortality* (n=2). Moreover, participants mentioned the different *appearance* (n=2) and according to this, the possible *movement and behavior* (n=1) as being different. More importantly, humans differ from robots since they are *self-aware* (Mind/Self-Awareness: n=7) and have metaphysical or transcendental characteristics such as having a *soul or spirit* (n=5). Accordingly, participants also described, as distinguishing or uniquely human characteristics and abilities, the human ability for *autonomy* (n=3), *creativity* (n=1), *charisma* (n=2), *individuality* (n=1) and most importantly *emotion* (n=9). Furthermore, humans have the ability for *(evolutionary) learning* (n=1) and are therefore more *flexible* (n=1).

Robot versus machine. Participants were also asked to name distinguishing characteristics of robots and machines. Six participants stated that basically there is no difference, since robots are machines or special types of machines. However, these participants also found characteristics which defined robots as being special and different from ordinary machines.

The most important factors seemed to be *artificial intelligence* (n=4), *mobility* (n=4), the ability to *interact* (n=2) and *communicate* (n=4). Moreover, participants stated that robots *resemble humans* (at least in parts; n=3) or just differ in *appearance* (n=1), can serve different purposes and are thus able to do *multi-tasking* (n=3). In contrast to ordinary machines, robots are more *complex* (n=1), *autonomous* (n=2) and are able to learn (*machine learning*, n=2).

In total, less than half of the participants stated that robots are basically not different from machines or just a special type of machine. And all participants found characteristics that distinguished a robot from a machine. The most prominent factor was artificial intelligence in different forms, such as autonomous locomotion and mobility, the ability to interact and communicate with humans and that robots are more complex and flexible than machines. When distinguishing robots from humans participants referred to the life cycle of humans and to their more metaphysical or transcendental characteristics, such as being self-aware or having a soul and therefore being more than the sum of their parts. It can be derived that robots have certain aspects of appearance that resemble humans (having arms and legs), or share certain abilities (communication, interaction, mobility).

3.4 Influence of culture, gender, and profession on perception and evaluation of robots

To address the research questions with regard to influences of culture ***(RQ8)***, gender ***(RQ9)*** and profession ***(RQ10)*** on participants' perception and evaluation of robots, interview answers were analyzed with regard to these differences. As reported in section 3.1 there were differences with regard to culture, but not regarding participants' gender or profession. However, cultural differences were only observable for specific questions concerning specific robots. There were differences with regard to the familiarity of robots. Compared to the Malayan participants, Germans perceived Nexi and AR as rather unfamiliar. In contrast, Germans judged Geminoid HI-1 as being more familiar. They also reported to be less negatively affected when meeting Geminoid HI-1 in the cinema compared to the Malayan participants. Moreover, participants' reactions towards meeting Nexi in the cinema were different in that German participants tended to be tenser. It has to be mentioned that CB2 reminded some Malayan participants of a Malayan ghost called Toyol which can be created using black magic and is often depicted as small, gray, and bald boy. This ghost sneaks into houses, steals things and makes mischief (cf. http://en.wikipedia.org/wiki/Toyol). Despite the fact that CB2 was frequently associated with this very unpleasant ghost and participants having obviously very negative reactions towards it, CB2 was not ranked as the most unpleasant robot by Malayan participants as it was by Germans.

Table 6: Likability rankings dependent on nationality (presented as ordered by the participants)

Rank 1	Rank 2	Rank 3	Rank 4	Rank 5	Rank 6	Meet robot
German participants						
Asimo	AR	Nexi	HRP-4c	Geminoid	CB2	Nexi
Asimo	AR	Nexi	Geminoid	HRP-4c	CB2	Asimo
Asimo	AR	HRP-4c	Nexi	Geminoid	CB2	Asimo
Asimo	HRP-4c	AR	Geminoid	Nexi	CB2	Asimo
Asimo	Geminoid	Nexi	HRP-4c	AR	CB2	Asimo
AR	Asimo	Nexi	Geminoid	HRP-4c	CB2	Nexi
AR	Nexi	HRP-4c	Asimo	CB2	Geminoid	Nexi
Nexi	Asimo	Geminoid	AR	CB2	HRP-4c	Nexi
Malayan participants						
Asimo	HRC 4P	AR	Nexi	CB2	Geminoid	HRP-4c
Asimo	HRC 4P	AR	Nexi	Geminoid	CB2	Asimo
Asimo	AR	HRP-4c	CB2	Nexi	Geminoid	Asimo
AR	Asimo	Nexi	HRP-4c	CB2	Geminoid	Geminoid
AR	Asimo	Nexi	HRP-4c	Geminoid	CB2	AR
AR	Asimo	HRP-4c	CB2	Nexi	Geminoid	Nexi
HRP-4c	Asimo	AR	Geminoid	Nexi	CB2	HRP-4c
HRP-4c	Nexi	AR	Asimo	CB2	Geminoid	HRP-4c

Moreover, there were differences observable with regard to the likability rankings of the robots when comparing German and Malayan participants. While for Germans HRP-4c was placed in the middle and lower ranks (rank 2-6), Malayan participants liked this robot more and placed it in the first ranks (rank 1-4). For Germans CB2 was most unlikable and was placed in the last or second to last rank. Geminoid HI-1 was not the most likable robot, but received rakings from rank two to six. In contrast, Geminoid was placed on the second to last or last rank by Malayans and CB2 was ranked on the last three positions. German participants chose either Nexi or Asimo to meet with, while Malayan wanted to meet HRP-4c, Asimo, Geminoid, Nexi or AR (cf. Table 6).

As mentioned previously, Germans were more direct and straightforward in their answers to the question of how they would feel if the interviewer were a robot. All of them directly abnegated this possibility and stated that they could just not believe that this could be possible. Malayan participants reacted with surprise to this possibility. They took longer to answer and tried to explain why they would not believe this possibility. Moreover, their answers were mixed. Some still stated they would not believe it, while others stated that they would be surprised, but it would be okay for them. There were no obvious differences with regard to the question of whether participants would like to have a doppelgänger or with regard to the questions asking for differences between robots, humans and machines.

Furthermore, neither gender nor profession showed significant influences with regard to the evaluation of the robot, nor did they influence the answers to more general questions.

3.5 Influence of age on perception and evaluation of robots

To address the research question of whether children perceive and evaluate robots differently from adults ***(RQ11)***, we also conducted interviews with 22 children. As described in section 2.1.2 the children belonged to two different age groups and were aged between 5 and 7 years, or between 10 and 11. Especially the younger children had difficulties in expressing their emotional states when explicitly asked for after the presentation of the pictures. Therefore, only the answers with regard to categorical perception of robots and the answers with regard to the question of robots replacing humans were analyzed in order to address the causes or explanations of the uncanny valley.

3.5.1 Categorical perception of robots and humans

Robot versus human. While participants in the adult sample mentioned a variety of different aspects which distinguish robots from humans, the answers of the children were less variant. The aspects unique to humans most quoted by the adults were *emotion*, *self-awareness*, *having a soul or spirit*, and *autonomy*. Children concentrated predominantly on physical aspects. The most important of these were that humans and robots are created from different *material* (metal versus flesh; n=10), differ in *appearance* (n=9), and in the quality of their *movement* (n=7) and *speech* (n=2). Some children demonstrated this by moving in a staccato manner or speaking robot-like (e.g. "Hello – I – am – a – robot."). Only three children mentioned *self-awareness* or the ability to think, and only one child stated that in contrast to humans, robots have no *emotions*. Four children stated that in general humans are more *flexible* and that they are *capable* of doing more things than robots.

Robot versus machine. Six children stated that there is basically no difference between robots and machines. However, out of these six subjects three added aspects such as appearance or mobility to distinguish between the two. Distinguishing aspects were quite similar to those mentioned by adults and included *appearance* (n=3), *mobility* (n=6), the ability to *communicate* (n=5), and that robots resemble humans (n=1), and are suited to different purposes (*multitasking*, n=3). One child mentioned that robots are more autonomous than machines.

3.5.1 Fear of being replaced

Children's answers to the questions regarding the fear of being replaced have been analyzed. Participants were asked their opinion on the question: "How would you feel, if I said now that I am a robot? Imagine I am a robot, how do you feel about this?"

In contrast to the adults, most children's answers were not a resounding statement of disbelief. Only two participants explicitly stated that they would not believe the interviewer. Some interviewees reported feeling a little afraid (n=6) or having unpleasant feeling (n=1) and/or that they experienced uncertainty (n=3). Four participants explained they would be surprised, but would not be afraid. Seven participants stated that this would be weird for them without explaining this statement further. Six participants reported that they would like the idea of the interviewer being a robot (e.g. "Great. (Why?) Because, if humans were robots that I would have a lot of fun with that, than I would be a robot, too, then I would have a friend that is a robot, then I would do a lot of things with him together. And if my brother was a robot, then I would have great fun, I would be very happy because I could play with him." Ch2; "Good. (Why?) Because you would be a woman-robot. (Ok, and would you be surprised, or would you find this creepy?) Surprised!" Ch3). Two explicitly mentioned that they liked the fact that the robot would be female (because the interviewer is female).

When participants were asked whether they would like to have a robotic doppelgänger two thirds liked the idea (n=15) and one third (n=7) disliked it. Children in favor of a robotic doppelgänger stated that they would like to have a playmate and that it would be fun to have a duplicate that dresses the same way and plays mix-up games with friends and parents (e.g.

“Yes, then I would have a sister who looks exactly like me. Then everybody would think I have – there are two NAMEs at home, and they find this funny and I would laugh and the robot would laugh, too. And then it puts on my clothes which we bought matching to mine and we go outside and the other kids laugh. […] And asks mother „Are you NAME?“ and the robots says „no. I am the robot. Name is over there.“ And then mama goes away and is peeved. (smiles)“ Ch1); “because…then we could…maybe play together and (laughs). Me and me. One NAME and another NAME. Hello NAME, hello NAME!” Ch2). Others mentioned that the robot could do things they themselves had not learned yet (e.g. “hmmm... Yes. (why?) Because, he could do everything that I don’t know.” Ch3). Children who disliked the idea mentioned concerns similar to those mentioned by the adults, for example, that they would have to share attention (e.g. “No, because they will mistake the robot for me and then they will play with him not me.” Ch4).

4. Discussion

The aim of this initial study was to address diverse open questions with regard to the uncanny valley in one comprehensive interview in order to gain a holistic view of participants’ attitudes towards robots in general, and their perceptions and evaluations of different humanoid and android robots in particular. Influencing factors frequently affiliated with the uncanny valley hypothesis such as the appearance and movement of robots, the context in which human-robot interaction takes place and characteristics of the participants themselves, i.e. gender, profession, culture and age, have been taken into account by the choice of stimulus material, interview questions and samples. Moreover, the study was aimed at reaching first conclusions on the importance of two possible causes and explanations of the uncanny valley, namely uncertainty at category boundaries and subconscious fears of being replaced and annihilation. For this purpose 16 German and Malayan adults and 22 German children in two age groups were interviewed. During the course of the interview participants were presented with pictures and videos of three humanoid and three android robots and asked questions with regard to their perception and evaluation of these robots. In addition, general questions asked for participants’ attitudes on diverse robot related topics. All the robots presented as stimulus material were considerably human-like, all of them had a human-like figure with a head, torso, arms and the majority with legs. Four robots had facial features (eyes, brows, nose, and mouth) and were able to show facial displays. The three android robots were covered with human-like silicon skin. Particularly these robots were frequently considered as falling into the uncanny valley. In the videos all the robots engaged in tasks usually associated with humans (doing chores, singing, dancing, conducting an orchestra, playing, introducing oneself, working on a laptop, sitting in a café) thereby implying certain abilities. Altogether, these robots were considered appropriate for exploring participants' reactions and analyzing them with regard to the uncanny valley.

4.1 Participants' immediate reactions towards the robots, their perceptions and evaluations

The uncanny valley phenomenon is most often referred to as a negative or even repulsed reaction. Participants in this study were asked how they felt when looking at the picture or video of a particular robot. To summarize, they showed very varying reactions towards the different robots. For some robots the reactions were overall very positive (e.g. Asimo), others elicited overall very negative reactions (e.g. CB2) and for some the reactions were rather mixed (e.g. Nexi). Elaborations on negative responses included fear, disgust, revulsion, sadness, empathy and pity. In addition, participants reporting negative and distressed feelings sometimes reported being highly irritated and confused, most often about the purpose of the robot (e.g. HRP-4c, Nexi) or about the general nature of the robot being a robot or a human (Geminoid HI-1). Participants felt uncomfortable at the thought of a society where robots would live among humans unrecognized. The reasons for negative responses varied, besides uncertainty about how to categorize the robot there were also other aspects of appearance. For instance, that CB2 looked alien-like or ghost-like with its grey skin, bald head and only three fingers or that Nexi's body was not covered so that wires and joints were visible. Especially for the robots with no general trend in the perception and evaluation, the answers were greatly influenced by the participants' prior experiences and their initial associations, which were also rather diverse. Besides the initial question about their emotional experience, participants were asked to imagine a possibly uncomfortable situation (sitting next to robot in a cinema). This question caused even more mixed answers, because answers depended on participants' general attitudes. Some participants found the general thought of any robot in a cinema disturbing, whereas others reported sometimes feeling okay with it and sometimes not, depending on whether they liked the robot or not. While most participants were immediately able to describe their emotional experience and indicate a valence, some participants seemed rather detached when looking at the pictures of the robots and stated feeling overall "neutral".

With regard to the uncanny valley, it can be concluded that not all android robots per se come together with strongly negative responses, because HRP-4c elicited rather positive responses. In fact, the appearance of the particular android played a big role. Geminoid HI-1 was often criticized by the participants as having an unfriendly facial expression. CB2's skin color looks unnatural and sick. In contrast, HRP-4c was said to be a "cute Japanese". This indicates that indeed the rules for attractiveness apply for very human-like looking android robots as suggested by MacDorman and Ishiguro (2006) and as was shown for virtual agents by Sobieraj (2012). Moreover, the character of negative responses can either be fear, disgust or pity, depending on the robot. Although they are still all negative reactions, the implications are different, because participants experiencing fear or disgust might refuse to use a system which could be different for participants experiencing pity. Moreover, these reported varying negative emotions suggest different causes for the occurrence of the emotion as well. While disgust might be a more deeply rooted and straightforward mechanism to avoid infection (cf. MacDorman, 2005a; Rozin & Fallon, 1987), empathy is "a complex form of psychological inference in which observation, memory, knowledge, and reasoning are combined to yield insights into the thoughts and feelings of others" (Ickes, 1997, p. 2).

With regard to the perception and evaluation of the robots, it can be concluded that they were evaluated in different dimensions. We asked for a general valence of participants' evaluations and for concrete evaluations with regard to safety, usefulness, and familiarity. In most instances, perceived usefulness was mentioned in coincidence with a generally positive evaluation. When participants' were unable to directly see or indirectly infer the purpose of the robot, the robot was also often evaluated negatively. Some participants explicitly stated that their likability ratings of the robots during the sorting task were directly connected to the functionality of the robots. Familiarity, however, was not directly connected to likability or a general positive evaluation. Likable robots could be both familiar and unfamiliar, as could be non-likable robots. However, participants mentioned that robots corresponding to their stereotype of robots were also more likable connecting familiarity to likability. As robots conforming to stereotype participants mentioned Asimo, AR and sometimes Nexi. These findings are of great interest with regard to the debate around the correct translation of the x-axis of the uncanny valley graph. As mentioned in section II.2, early translations of the uncanny valley translated *sinhwa-kan* with familiarity while newer translations refer to it as likability. The lack of interdependence of likability and familiarity puts previous results showing an uncanny valley into question. In further studies, both concepts likability and familiarity should be used to further examine the uncanny valley effect.

4.2 Influence of appearance, movement, and context on participants' perception and evaluation of robots

As already mentioned above the *appearance* of the particular humanoid or android played a major role. Participants seemed to apply the same rules of attractiveness to the android robots as they do for humans, which explains the positive evaluations of HRP-4c and the negative ones for CB2 and Geminoid HI-1. However, resembling humans in the way the androids presented in this study were designed did not find much favor. Although appreciated as a demonstration of technological advancement, the resemblance to humans was perceived as unnecessary and sometimes even inappropriate. Participants preferred functionality, and the appearance should match the functionality. It seems that very human-like appearance is not strongly associated with functionality since participants perceived Geminoid HI-1 as rather useless, although the robot could be assumed to have the potential for doing the same things as humans. Moreover, participants showed preferences for sleek design. While Asimo was frequently liked, also for its design, Nexi and AR were criticized, because they were uncovered, or too bulky. With regard to the importance of different parts of the robots' bodies, interviewees referred to the face, eyes, hands, and voice as being important. However, there was no general agreement among all the participants as to whether a robot should feature these aspects of appearance or not. For instance, while some participants liked facial features, others preferred robots without facial features, like AR and Asimo. Also exaggerations of facial features according to the baby-scheme as could be found for CB2 and Nexi, elicited mixed responses. Since the robots are indeed very different, there were hardly any general tendencies observable for what aspects of appearance were evaluated positively. However, there is agreement that every aspect of appearance of the robot should serve a specific purpose and that merely human appearance without a connected functionality is not appreciated. Moreover, the robots' height seems to contribute to the perception of possible danger.

Besides appearance, *movement* was a highly influential factor. In general, high quality of movement in terms of smoothness and adequate velocity was evaluated positively. Moreover, participants generated expectations about the robots movements when seeing a picture and a mismatch of expectation and actual observed movement resulted in either surprise or disappointment. For instance, although CB2 evoked negative evaluations, participants were surprised by its very lifelike actions. In general, expectations were greater for more human-like robots. With regard to the uncanny valley phenomenon it was surprising that although the majority of the participants reacted with distress when they were reassured that Geminoid HI-

1 is a robot, some of them were quite relieved at seeing the video and reported feeling more relaxed afterwards. On the one hand participants were disappointed by Geminoid HI-1's limited movements. On the other hand the movement also provided the necessary cue to clearly categorize Geminoid HI-1 as a robot, making it more predictable. This reflects how complex the interplay of appearance and movement is. Unlike the general assumption that unrealistic movement in very human-like androids causes uncanny valley related reactions, it seems more likely that realistic movement would cause these reactions, because they exacerbate discrimination processes.

Moreover, limited movement was either seen as appropriate for less human-like robots or as disappointing. In general, participants had quite high expectations about robots probably induced by robots' capabilities shown in movies as was mentioned several times.

In addition, participants referred to the different *contexts* in the videos to elaborate their evaluations. Participants' initial thoughts about an appropriate and inappropriate context for human-robot interactions during the video evaluations were also reflected in their answers to the questions explicitly asking for these contexts. In general, participants envisioned robots being used for the classic *dangerous-dirty-dull* tasks: boring and repetitive tasks (e.g. assembly line in a factory, household chores), dangerous tasks (e.g. exploring hazardous areas after disasters), and dirty tasks (e.g. garbage collection, household chores). Interestingly, a minority stated that they would prefer non-human-like robots for these tasks, because forcing a human-like robot to do *dangerous-dirty-dull* tasks would feel like slavery. Indeed the human-like appearance seems to trigger enough emotional responses to put participants in moral conflicts. A minority of the participants experienced difficulties in imagining what robots could be useful for or had problems imagining the robots presented in contexts other than those in the videos. As a result, most participants discussed the positive and negative aspects of the robots in the context of doing chores, which was also mentioned frequently as a very good application field for robots. Moreover, participants mentioned application fields dependent on the robots' capabilities, ascribing more sophisticated tasks to more human-like or communicative robots, respectively.

4.3 Conclusion with regard to explanations for the uncanny valley phenomenon

In the course of participants' elaborations on adequate and inadequate application fields for robots, some of the concerns raised were tangent to possible explanations for the uncanny valley effect. Some participants suggested that by letting robots taking over non favored jobs, the humans replaced should be free to do something they like better, and even more important, they should only be replaced when they are guaranteed a new and better job. Although this statement seems to touch MacDorman's and Ishiguro's (MacDorman, 2005; MacDorman & Ishiguro, 2006, section II.3.3) suggestion that androids trigger subconscious fears of being replaced, this concern was raised for robots in general and was not related to statements related to some kind of identity theft or the fear of being replaced physically. However, it expresses that we might see humans more holistically, not only as a physical being, but also as economic agent. Thus, the subconscious fears of being replaced might in the future be referred to in a broader sense including all aspects describing human identity. This is also reflected in the statements denying robots the ability and right to engage in tasks in fields where humans push their boundaries in order to pursue mastery or virtuosity such as sports, arts and music. Interviewees' answers on the question of robotic doppelgangers were more directly connected to the fear of being replaced. Some participants were very sensitive to the question of robots living among humans unrecognized, although there was general agreement that this is not yet possible. Some, but not all, participants expressed feelings of unpleasantness at the thought of sharing the attention and love of others with a robotic doppelgänger. Others were content with a robotic doppelgänger as long as they were in control of it. Moreover, the majority was not in favor of using a robotic doppelgänger as tele-presence tool. Some participants referred to, what were in their eyes, negative examples from movies like *Surrogates* (Handelman et al., 2009) in which people stay at home and interact with each other through their robotic doppelgängers which they control by the use of a fully immersive tele-presence device. Altogether, robotic doppelgänger were regarded as science fiction rather than a real possibility leaving participants' statements hypothetic.

In addition, interview questions addressed the question of whether robots are at category boundaries and thereby eliciting states of uncertainty (Ramey, 2005, 2006; section II.3.3). The stereotype of a robot varied among the participants. The majority described a stereotyped robot as humanoid and referred to relevant examples from movies (Sonny from the movie iRobot, C3PO from Star Wars, Gundam, Transformers), but some participants had not only one in mind, but a variety of robots and some participants described exclusively more functional robots (e.g. R2D2). Accordingly, the majority of the participants evaluated their stereotype of robots as being at least a little human-like to very human-like. When asked what differentiates robots from humans and machines, respectively, participants mentioned very different concepts. Although most of the participants knew that robots are a kind of machine, all participants found distinguishing characteristics with artificial intelligence (autonomous locomotion, mobility, ability to interact and communicate with humans) being the most prominent one. Descriptions depict robots as superior machines which can be used for multiple purposes and not just one single purpose. Moreover, robots are often characterized by their human-like appearance. Robots were distinguished from humans by referring to the life cycle of humans and to more metaphysical or transcendental characteristics such as being self-aware or having a soul, being creative. The general consensus is that robots (and especially androids) might try to resemble humans in terms of appearance and abilities, but humans are too complex and most importantly more than just the sum of their parts. However, participants implicitly revealed that there were many overlaps between humans and robots with regard to appearance and certain abilities.

4.4 Influence of culture, profession, gender and age on participants' perception and evaluation of robots

Participants' interview answers were also analyzed with regard to influences of culture, gender, profession and age.

Gender and *profession* did not show influences with regard to the perception and evaluation of the robots nor did they influence the answers to the more general questions.

There were, however, differences with regard to *culture,* but only for certain aspects of the interview. It is important that these differences are tangent to the uncanny valley related concepts of *familiarity* and *likability*. First, differences with regard to the familiarity of robots were observable concerning Nexi, AR and Geminoid HI-1. German and Malayan participants also reported different feelings when sitting next to Geminoid HI-1 or Nexi in the cinema. Second, there were differences observable with regard to the likability rankings of the robots showing that Germans tended to like HRP-4c and CB2 less and to like Geminoid HI-1 more than Malayans. Moreover, the two groups showed different preferences for meeting a robot. Some Malayan participants reported that CB2 reminded them of a very unpleasant Malayan ghost causing very negative reactions towards it. However, CB2 was not ranked as the most unpleasant robot by Malayan participants as it was by Germans. Furthermore, Germans seemed to be more resolute in their answers, stating that they did not believe that the interviewer could possibly be a robot. In contrast, Malayan participants reacted more surprised, took longer to answer and tried to explain why they would not believe this possibility. Some left this option open and stated they would be okay with it. It is however questionable whether Malayan participants really believed that this might be an actual possibility or whether they just tried to be polite to the interviewer. Since the interviewer belonged to another cultural group (Germans) they might have wanted to avoid offending the interviewer. Moreover, the interviewer was a totally unknown person. Although introduced to them by the Mercator Office at UKM as a visiting scholar most of the Malayan participants had no prior contact to the interviewer. In contrast, the German participants were recruited on campus and engaged in email exchange and telephone calls with the interviewer prior to the interview to arrange a date and time. Thus the difference could be an effect of familiarity with the interviewer.

To examine *age differences* in the perception and evaluation of robots interviews with 22 children were conducted. Due to the children's difficulties in expressing their emotions only the general questions concerning possible explanations for the uncanny valley phenomenon have been addressed in the analysis. A first observation is that similar to the adults some children stated that there is basically no difference between robots and machines, but still all participants found distinguishing aspects in appearance, mobility, multitasking, and the ability to communicate being the most prominent ones. However, when distinguishing robots from humans, the children's answers were less varied than those of the adults. In contrast to the adults, children concentrated less on metaphysical concepts, but rather more on physical aspects and mentioned material (metal versus flesh), appearance, quality of movement and speech. Self-awareness or emotions were mentioned by just four children. These results show that children and adults conceptualize humans differently. An adults' concept of humans is more comprehensive than that of a child, including more aspects of humanness and uniquely human abilities that are intangible and elusive. Perhaps because of the children's concept of humans which had great overlaps with the characteristics of android robots (because they have a similar appearance, and the quality of movement and speech can be quite high), children might also have reacted differently from adults with regard to the question of how they would feel if the interviewer was a robot. Reactions were very mixed, from extreme dislike of the idea to liking it. Also in contrast to the adults, the majority of the children liked the idea of having a robotic doppelgänger. Only one third of the children mentioned fears of being replaced by the doppelgänger in terms of having to share the attention of friends and parents.

5. Limitations

Certain limitations have to be mentioned with regard to this study. First, in order to comprehensively address a variety of open questions in the course of the interviews, the stimulus material have had set limits, otherwise the interviews would have been too long. Thus, only six robots - three humanoid and three android - were included in the study leaving out mechanical robots. Thus no conclusions can be drawn on participants' perceptions and evaluations of more mechanical looking robots or zoomorphic robots. In addition, robots vary greatly in their appearance, so that other aspects of appearance such as color and shape (round shapes versus squared shapes) might elicit other evaluations than those reported in this interview.

A comparison of adults and children's perceptions of the individual robots was not possible, because some children, especially of the younger age group of 5-7-year-olds, had difficulties in expressing their feelings when asked for them. It seems that interview questions would have had to be even more simplistic to gain meaningful answers or other measures found to examine children's emotional responses such as nonverbal behavior. However, in further analyses the older age group could be analyzed separately and compared with the adults.

Also, with regard to the sample, it has to be mentioned that the Malayan sample was not perfectly balanced with regard to gender and profession, therefore hindering an examination of gender and profession differences. This is due to the limited time frame at UKM University in which the interviewer recruited participants. It was especially difficult to attract students to take part in interviews because most students thought they spoke insufficient English and therefore refused to take part in interviews. This resulted in a sample of predominantly lecturers who were also a bit older on average than the German sample which mostly included Master and PhD students.

Most importantly, the results of this interview study are of a descriptive nature and are intended to give first qualitative insights into how humanoid and android robots are perceived with regard to a variety of aspects. Thus the results of this study can hardly be generalized. Hence, reported differences with regard to culture and age also do not claim to be statistically significant, but rather a springboard for further discussion and examination of influencing factors for uncanny valley related responses.

Lastly, participants saw pictures and videos of robots but did not engage in real interactions with robots. Furthermore, some of the questions also required them to imagine how they would react in hypothetical situations. These questions (e.g. sitting in a cinema next to a robot) were used to create (imagined) situations of human-robot interaction designed to provoke an emotional response, in which they succeeded. However, participants' actual reactions towards the robots presented could be quite different.

IV. STUDY 2: OBSERVATIONAL FIELD STUDY ON HUMANS INTERACTING WITH AN ANDROID

1. Introduction

In the course of the first study quite a number of open questions with regard to the uncanny valley, its underlying mechanisms and influential aspects were addressed in one comprehensive interview. This was in order to gain a holistic view of participants' attitudes towards robots in general, and their perceptions and evaluations of different humanoid and android robots in particular. Moreover, the interview results highlighted some uncanny valley related concepts and aspects shown to be highly influential, one of which was movement. Participants generated expectations about a robot's movement based on the pictures they saw. For instance very human-like robots elicited higher expectations in terms of smoothness and velocity and in general with regard to lifelikeness. A surprising finding was that although the majority of the participants reacted with distress when seeing a picture of Geminoid HI-1, some participants stated being relieved after the video, because the movement provided the necessary cue to clearly categorize Geminoid HI-1 as a robot, making it more predictable. However, participants also reported being disappointed, because after the picture they expected more sophisticated movement. This example shows the complexity of the interplay between appearance and movement. While androids are frequently suspected of falling into the uncanny valley the three androids presented in the interviews elicited very different feelings and evaluations, respectively. Moreover, based on participants' statements, the general assumption that unrealistic movement in very human-like androids causes uncanny valley related reactions does not seem to be conclusive. In contrast, it appears more likely that very realistic movement would cause these reactions, because they exacerbate discrimination processes. And hence limited or unrealistic movement might reassure people about the nature of the robot at hand. As in most studies addressing the uncanny valley, one limitation of the interview study was that participants were shown fictional material such as pictures and videos but they did not engage in real interactions with the robots. Thus, the influence of movement in actual human-robot interaction will be examined in more detail in this second study. The study will explore how an android's movement influences participants' perception of the android and their behavior towards the android. While a number of studies on the uncanny valley effect have been conducted with android robots in laboratory settings resulting in uncanny valley related responses, they share the fact that interactions are scripted and that participants already knew that they would be interacting with a robot. Moreover, the interaction times were restricted. Only little work has been done on androids in field trials and there is no knowledge of how humans would react to or interact with an android robot in natural unscripted situations. Therefore, this second study will focus on two specific aspects of the uncanny valley phenomenon. First, whether uncanny related responses are also observable in human-android interactions in the field, where participants are not prompted about the robotic nature of the android and where the situation does not follow predefined scripts will be explored. And second, the influence of android movement on uncanny valley related responses will be examined in this real world scenario. The following sections will briefly review previous work with android robots in laboratory (section IV.1.1) and field settings (section IV.1.2). Subsequently, the guiding research questions and hypotheses of this second study will be presented in section IV.1.3.

1.1 The influence of movement in studies with android robots

A number of studies have been conducted with android robots in laboratory settings. As reported in section II.4.2, Noma et al. (2006) showed participants for one or two seconds, a human woman or the female android showing either no movement or natural movements such as posture shifts, subsequently analyzing whether participants were able to tell whether they saw a human or a robot. Participants were most often able to identify the human woman as human, followed by the moving android and the static android. The displayed behaviors were rather limited (eye-blinking, posture shifts), because they imitated a human sitting naturally and the exposure time was very short. This also indicates that limited movement helps to categorize androids more easily as robots. However, there was no evaluation of the robots likability or an examination of participants' emotional responses. Moreover, the study did not involve actual interaction and the time frame of seeing the human or android was quite short. The results could have been quite different if the android had been presented for a longer period of time.

A similar paradigm was used by Bartneck et al. (2009) who asked participants to answer some questions posed by either a human or an android, both displaying either natural or limited behavior. Participants evaluated the human and android with regard to human-likeness and likability after a very brief interaction time. Although in this case the human was rated as more human-like, this was not reflected with regard to his likability. In addition, effects for movement were inconsistent: although the human with limited movement was rated more negatively, there were no effects with regard to the android robots.

A series of studies examine the influence of motion in interactions with androids by measuring participants’ gaze and gaze aversion (Minato et al., 2004; Minato et al., 2006; Shimada et al., 2006; Shimada & Ishiguro, 2008). In these studies, participants were confronted with a human and either androids with different qualities of movement or an android and a humanoid robot. To summarize, the analysis of participants’ gaze behavior (fixation and gaze aversion) revealed differences in gaze patterns between humans, android robots and mechanical robots. However, the differences observed were not consistent across studies although researchers used the same paradigm and in some studies even the same android robot. This series of studies showed that movement influences participants’ behavior, but across studies the results deliver only a fuzzy picture of the direction of the effects. Altogether, these results suggest an influence of movement on participants’ evaluation of human-likeness as well as their actual behavior towards robots.

With regard to the critique that the uncanny valley could only be a short-term reaction which can be overcome by habituation (c.f. Bartneck et al., 2007; Brenton et al., 2005; Ramey, 2006; Pollick, 2010) it has to be acknowledged that Noma et al. (2006) and Bartneck et al. (2009) used very short time frames for their interactions. Moreover, all presented studies were highly scripted with regard to the possible interactions. Thus, longer interactions with more degrees of freedom might result in very different evaluations and nonverbal behavior, supporting the critique that the impact of the uncanny valley effect could have been overestimated (cf. critique by Bartneck et al., 2007 and Pollick, 2010).

1.2 Previous field studies with Geminoid HI-1

Although the robotics community does a lot of field trials exploring the acceptability of robots in public spaces, there is hardly any work on field trials with androids. However, in the fall of 2009, the annual “ARS Electronica” festival in Linz, Austria, featured the android Geminoid HI-1 and its creator, Hiroshi Ishiguro, as a special attraction in the overall context of the arts festival (cf. Figure 17) and in the course of the exhibition data was collected on human-android interaction in real life settings. Before the official beginning of the festival, Geminoid HI-1 was placed in the Café CUBUS in the ARS Electronica building. The android robot sat behind a table, with a laptop in front of it and an information desk about Kyoto and its attractions beside it (see Section 3 for a more detailed description of the setting). During the festival itself, it was installed as an exhibit in the basement of the ARS Electronica building. Within both settings, different studies (including the study reported in the current paper) took place, investigating diverse research questions. Two other studies of this series and their results will be presented in the following.

Figure 17: Geminoid HI-1 with its human counterpart and originator Prof. Hiroshi Ishiguro

Within the Café CUBUS setting, 30 visitor dialogues with Geminoid HI-1 (teleoperated by a fellow participant) were analyzed with regard to the identity perception of the interlocutor facing Geminoid HI-1 and identity creation of participants teleoperating the robot (Straub, Nishio, & Ishiguro, 2010). The results show the tendency in both -the teleoperator and the interlocutor- to ascribe an identity to the android robot Geminoid HI-1, independent of the identity of the person controlling the robot. The authors conclude that the humanoid features of Geminoid HI-1 elicit assumptions on the part of the user regarding the robot's (human-like) character, expected reactions and conversational skills, which is therefore treated as a social actor (c.f. Nass, Steuer, & Tauber, 1994; Nass, Moon, Morkes, Kim, & Fogg, 1997). However, the analysis of the speech sequences also revealed that Geminoid is placed as an "entity 'in-between'" (Straub et al., 2010, p. 144), referred to with anthropomorphizing words and human characteristics as well as robotic characteristics. This finding seems to be connected to the argument of Ramey (2006), who states that the categorization of objects and experiences is imperative for humans. Robots, however, cannot be categorized easily and reliably into either "human" or "machine" or "alive" and "not alive", because they are at the boundary between these categories (c.f. section II.3.3).

Becker-Asano, Ogawa, Nishio, and & Ishiguro (2010) report on interviews conducted with 24 visitors to the festival who previously interacted with Geminoid HI-1 within the exhibition. When asked to describe the android robot, the visitors gave more positive descriptions of

Geminoid HI-1 (e.g. very human-like, striking verbal skills, terrific, very likable) than negative descriptions (e.g. surreal, quite thick fingers, too obviously robot-like, a bit scary). When asked directly about their emotional reactions towards the robot, 37.5% (9 participants) of the visitors interviewed reported an uncanny (or strange or weird) feeling, and 29% (7 participants) stated that they enjoyed the conversation. Interestingly, in five of these cases, the interviewees' feelings even changed during the interaction. For example, one reported that the interaction was "amusing" at first, but that he experienced a "weird" feeling when he discovered that his interaction partner was actually a robot. Most descriptions of Geminoid HI-1 were related to its outward appearance, with negative attributes being expressed here in particular. Negative descriptions also referred to imperfections in its movements. With respect to emotional reactions, fear was found to be the predominant emotion which relates to the uncanny valley hypothesis, because in theories on emotion fear is regarded as indicating a person's submissive behavioral tendency to withdraw from a threatening or unfamiliar situation (cf. Ortony, Norman, & Revelle, 2005), an assumption which is in line with the work of MacDorman and colleagues (MacDorman, 2005b; MacDorman & Ishiguro, 2006). The authors conclude that "Geminoid HI-1's inadequate facial expressivity as well as its insufficient means of producing situation-appropriate social signals (such as a smile or laughter, […]) seems to impede a human's ability to predict the conversation flow" (Becker-Asano et al., 2010, p. 127), thus causing feelings of not being in control of the situation.

1.2 Research questions & hypotheses

With regard to previous work on the uncanny valley hypothesis most studies are limited in their explanatory power, as they use pictures and videos instead of real robots or utilize only one single robot. However, given the limited number of existing android robots, their availability and the immense time and cost involved in conducting a comparative study using several of these robots, research in the near future will still be limited and only be able to examine specific aspects of the uncanny valley phenomenon. Also, the present study will focus on two specific aspects of the uncanny valley phenomenon. Based on the results from Study 1 and regarding the lack of studies examining open-ended, unscripted, real-life interactions with android robots, this second study focuses on the exploration of whether *uncanny related responses are observable in unprompted and unscripted human-android interactions in the field*. Moreover, *the influence of android movement on uncanny valley related responses* will be examined in this real world scenario. In order to explore both aspects, a secondary data analysis was performed on data collected during an extended exhibition of an android robot in a public space. Since the android was presented in different settings and in different operational modes it was possible to analyze the data analogue to a quasi-experimental observational field study with variations in the android's behavior. The study focuses on the investigation of how people react towards an android robot in a natural environment dependent on the behavior displayed by the robot. Hence, Study 2 presents data on unscripted interactions between humans and the android robot "Geminoid HI-1" (cf. Figure 17) which was analyzed with regard to the participants' nonverbal behavior (e.g. attention paid to the robot and proximity).

In the previously presented Geminoid HI-1 studies, the visitors were prompted to talk about the robotic nature of Geminoid HI-1 or about the experimental situation, because it was explicitly placed at the festival as an exhibit, or subjects were invited to take part in a conversation with a tele-presence robot, respectively. The present study also took place within the described setting of the ARS Electronica Festival. In contrast to the studies of Straub et al. (2010) and Becker-Asano et al. (2010), however, participants were not informed about the robot. Thus, an analysis of these unprompted, unscripted interactions might reveal different reactions towards the robot. Studies utilizing easily displayable commercial robots (e.g. von der Pütten, Eimler, & Krämer, 2011; Sung, Christensen & Grinter 2009; Sung, Grinter, & Christensen, 2010), mobile robots (e.g. Weiss et al., 2010) or humanoid robots (e.g. Hayashi et al., 2007; Kanda, Sato, Saiwaki, & Ishiguro, 2007; Shiomi, Kanda, Ishiguro, & Hagita, 2007) in field studies had already revealed that participants show huge inter-individual differences in their behavior towards these robots. Moreover, the interviewees' answers in Study 1 demonstrated that although participants showed a general evaluation tendency for some robots, there were also robots eliciting a great variety of responses. Perceptions and evaluations were also influenced by culture and gender. Thus, it can be expected that inter-individual differences in participants' behavior as well as in their evaluations will also be found in interactions with android robots. Since interviews only allow for the assessment of reactions that are under conscious control or upon which the participants are able to reflect it, is important to combine interviews with more implicit measures such as participants' behavior. Besides the studies examining eye gaze which showed no clear pattern of uncanny valley responses, what has not yet been analyzed in depth is the human interlocutors' nonverbal behavior. Since nonverbal behavior is more direct and spontaneous, an analysis of participants' nonverbal behavior might offer valuable clues as to the nature of human-robot interaction.

To summarize, how people react towards an android in unprompted and unscripted interactions and whether the robot's behavior (still vs. moving) influences participants' nonverbal behavior will be examined, leading to the following research question:

RQ1: How do people behave towards robots in a natural environment in unscripted and unprompted situations?

RQ2: Is the participants' nonverbal behavior influenced by the robot's behavior?

Noma et al. (2006) demonstrated that in the very short time frame of two seconds people were able to distinguish a human from a nonmoving android, but had problems telling a human from a moving android apart. The results of the interviews in Study 1, however, suggest that movement can serve as the necessary cue to be able to categorize an android as a robot. Participants in the interview study saw 30 seconds of video material. Since the displayed behavior of the robot is not as perfect as its outer appearance suggests, it can be assumed that people encountering the moving android will more easily recognize that they face a robot, and hypothesize:

H1: People encountering the moving android will more easily recognize Geminoid HI-1 as a robot than people encountering a still android.

However, according to the uncanny valley hypothesis moving objects will elicit stronger uncanny valley responses than still objects. Thus the following hypothesis is posed:

H2: People encountering the moving android will more often report feelings related to the uncanny valley effect than people encountering a still android.

2. Method

2.1 General setup

Prior and during the Ars Electronica Festival 2009 Geminoid HI-1 was placed in two locations at the ARS Electronica Center (AEC) in Linz. The android robot was on display as an exhibit during the festival in the basement of the AEC and prior to the festival it was placed in the Café CUBUS which is also part of the AEC and a well-known tourist café. During the whole time period data were collected for different purposes using different set-ups.

The data analyzed for the purpose of this second study was collected during Geminoid HI-1's time in the Café CUBUS from the 10^{th} to the 30^{th} of August. From this time period the eleven days where Geminoid HI-1 was displayed in the same setting were chosen: the android sat on a chair behind a small table with a laptop in front of it in order to give the impression of a working visitor (cf. Figure 18). Next to the robot, people could find information material about traveling to Japan. The scene was video-recorded from five camera perspectives: one behind the android to record participants just in front of it (cf. Figure 19), one facing and recording the android (cf. Figure 20) and three cameras covering the rest of the room.

People were not given any hints that they might encounter a robot within the café. Most of the guests entered the café using the elevator. They then passed the robot on their way to the bar, where the interviewer asked them to participate in a short interview (see Figure 18). Some guests came from the stairway ("behind" the yellow wall in the direction of the bar) or from the outside patio.

Figure 18: Setup with Geminoid H1 in the Café CUBUS

Figure 19: View from camera behind Geminoid HI-1

Figure 20: Camera view recording Geminoid HI-1

2.2 The android Geminoid HI-1 in different conditions

Geminoid HI-1 is an android robot and a duplicate of its scientific originator Hiroshi Ishiguro (HI). Geminoid HI-1 was designed to function as an embodied interaction tool in a human shape, which can be controlled from a distant location by teleoperation. The robot is covered by silicone skin with a natural skin tone, wrinkles etc. Geminoid HI-1 is able to show facial expressions and move its head, torso, arms and legs driven by 50 pneumatic actuators (Nishio et al., 2007). The robot features idle behavior, which includes breathing, eye blinking and in some cases posture shifts and was designed to express animation. Further expressive movements can either be separately programmed or executed in real time via teleoperation.

During the eleven days of data collection for this analysis, Geminoid HI-1 was presented in two different conditions, which are listed in the following.

Still condition. Geminoid HI-1 was presented in the *still mode*, in which the robot was merely looking down at the laptop in front of it, ignoring passersby. It showed the above-mentioned idle behavior.

Moving condition. In the *moving mode*, Geminoid HI-1 looked up when the participant looked straight in its direction or more precisely in the direction of the camera behind Geminoid HI-1, which used face-tracker software. The face-tracker software module was an extension of the OpenCV-based "Face Detection" source code (OpenCV Wiki). It tracked one or more frontal faces over a sequence of images taken from a video stream, allowing Geminiod HI-1 to follow one particular visitor with its gaze, even if he or she was moving slightly. Eight to ten times per second, the algorithm checked with the previously stored information about recognized faces at the very same position. When a previously recognized face stayed in the same place and kept looking frontally into the camera, the algorithm gave this face a one-step-higher priority. If a new person joined the situation and faced the camera frontally, the algorithm started the same procedure of counting up (beginning with priority zero) for the new face. A priority shift took place when the “old” face broke eye contact with Geminoid HI-1, because, for instance, the subject turned to face the newcomer. In this case, the “old” face was no longer observed. The new face then had a higher priority and Geminoid HI-1 faced the newcomer. When nobody interacted with Geminoid HI-1 and the algorithm did not recognize any faces, Geminoid HI-1 returned to looking down at the laptop.

Furthermore, seven participants interacted with the human counterpart of Geminoid HI-1, *Prof. Hiroshi Ishiguro*, who was sitting at the very same table as Geminoid HI-1 working quietly until he was addressed by the subjects.

Table 7 shows the distribution of subjects across conditions. As people went to the café to enjoy their free time and not with the intention of taking part in an experiment, it was not possible to ensure an equal distribution, because of the dependence on their willingness to participate in the interviews. The experimental design, however, was not the most important aspect of this study, because the investigation of the general reactions towards Geminoid HI-1 was also important. Since the group of participants interacting with Prof. Hiroshi Ishiguro is too small to compute comparisons with the other experimental groups, results will be reported anecdotally in a separate section (section IV.3.2.6).

Table 7: Distribution of subjects across conditions

Geminoid HI-1	Hiroshi Ishiguro
still: *n*=30	
moving: *n*=45	n=7
TOTAL N=82	

2.3 Interviews

On 11 of the 20 days, passersby were asked to participate in an interview. The interviewer addressed the participants with the following standardized sentences: “Hello. We would like to conduct a brief interview with you if you have a moment. It does not take longer than ten minutes and you would be volunteering to contribute to scientific research.” If participants asked what the interview was about, the interviewer told them the following: “The interview is about your personal experience within the last five minutes since you entered the café. We won’t ask personal questions and you may withdraw from the interview at any time without giving reasons for withdrawal”. The interviewer stood at the entrance to the bar of the Café CUBUS, recruited participants and guided them into a quieter corner of the bar. From the moment of recruitment, participants had no possibility of looking back into the room where Geminoid HI-1 and the information desk were placed. The interview was held in German or if necessary in English. First, subjects were asked to provide some demographic information (age, gender, nationality, profession). They were also asked whether they work at the AEC or had been in the café CUBUS before. Then, the interviewer asked whether they had noticed the information table next to Geminoid HI-1. If the participants gave an affirmative answer, they were requested to describe the table. If they had not noticed the table, they were asked whether they had perceived anything unusual or special when they entered the café. From these follow-up questions, the information was derived whether the interviewees had recognized the robot or mistaken it for a human being. As the final question all participants were asked whether they happen to know the robot Geminoid HI-1. Participants were then debriefed and thanked for their participation.

2.4 Analysis of videos

Eighty-two subjects who agreed to be interviewed and videotaped were identified within the video material. Their interaction sequences were extracted, starting from the moment of the subjects’ first appearance until they were recruited and guided into the next room by the interviewer. The video material was annotated in ELAN (Max Planck Institute for

Psycholinguistics, Nijmegen, The Netherlands; http://www.lat-mpi.eu/tools/elan/, Wittenburg, Brugman, Russel, Klassmann, & Sloetjes, 2006). Different behaviors of the participants were assessed. First, the total time was annotated for which people appeared in the videotaped area (which was coded as *appearance time*) and had the possibility of noticing the info table and the robot and engaging in interactions. Then participants' attention directed towards Geminoid HI-1 was annotated. In this category, two different behaviors were subsumed: when subjects were in the direct vicinity of Geminoid HI-1, gaze behavior was observable and the eye contact established with Geminoid HI-1 was coded; when participants were further away, the amount of time for which they faced Geminoid HI-1 frontally was annotated. Both times were summed up as *attention directed towards Geminoid HI-1*. In addition, *participants' verbal behavior* was coded. It was assessed whether, and if so for how long, they talked to Geminoid HI-1, to third persons or said something unrelated to the situation. Furthermore, participants' *behaviors which attempted to test Geminoid HI-1's capabilities and reactions* were coded, e.g., waving in front of the robot's face, grimacing or making a funny face, raising eyebrows, taking a picture, etc. Lastly, participant's *proximity* to Geminoid HI-1 was measured. Proximity was always coded using the same camera perspective (camera 1) so as to guarantee reliable coding and was based on previously defined proximity areas, namely the "outer area", the "vicinity area", the "adjacencies or table area" and "touch", which are illustrated in Figure 21. The proximity areas were identified using landmarks which are easily detected in the videos and did not change during the cause of the experiment. The proximity areas are very close to Hall's proximity zones (Hall, 1966; Hall, 1968) of the intimate space (<0.46m = touch), personal space (<1.22m = table area), social space (<3.66m = vicinity area) and public space (>3.66m = outer area).

The amount of "eye contact" established by Geminoid HI-1 was assessed (looking up and facing a participant). On the one hand, this was done to ensure that in the *moving condition* Geminoid HI-1 was really looking up. On the other hand, the amount of eye contact established by Geminoid varied in the *moving condition* depending on the number of participants surrounding Geminoid HI-1 and participants' eye contact. Furthermore, it was coded whether there was a group situation when the participants encountered the robot (Geminoid HI-1 is alone vs. Geminoid HI-1 is surrounded by visitors when subject arrives) and whether the participants were in company (subject is alone vs. in company) when they entered the café.

Ten percent of the coded video material (videos of 10 participants) was coded by a second rater. The ratings were checked for agreement between the two raters using the in-built function in ELAN for comparing annotators. Within this function, the beginning time and end time of each annotation were given, and the amount of overlap, the total extent (time from lowest beginning time up to the highest end time) and a value indicating the agreement was calculated (overlap / extent) for each category in each video, which were then averaged over all 10 videos used for cross-coding. The inter-rater reliability values were as follows: 96% for the category “appearance time of participants”, 86% for the category “attention to Geminoid HI-1”, 86% for category “Geminoid HI-1’s eye contact with participant”, and 94% for category proximity. Annotators agreed 100% on the occurrences of specific behaviors (such as talking to Geminoid HI-1, waving hands in front of the robot’s face, taking pictures, grimaces).

Figure 21: Proximity areas

2.5 Sample

107 guests were interviewed, of whom 98 (38 male, 60 female) agreed to be audio- and videotaped. Their age ranged from 8 to 71 years (M=38.43, SD=14.98). The majority were Austrians (81), followed by visitors from Germany (12), Italy (2), Spain (1), Belgium (1) and the Netherlands (1). Nine participants were retired, 20 were school pupils or university

students, and 61 were employees. Eight participants did not indicate their profession. From these 98 volunteers, 16 interacted with Geminoid HI-1 when it was remote-controlled by a confederate. These data sets were not included into the analysis, because there was too much variation in Geminoid HI-1's behavior. Moreover, seven participants interacted with Prof. Hiroshi Ishiguro. The sample size of this group was too small, thus, these results will be reported separately. The remaining 75 data sets were included for the analysis of interviews and behavior.

Although the Café CUBUS is part of the AEC, it does not only attract visitors to the Center. Since it offers high class cuisine, unique architecture and an outstanding view over the Danube and the local recreation area next to the river, it has many frequent guests as well as tourists coming in. Fourteen participants stated that they had visited the café before, while some stated that their travel guide recommended the café. Thus, it can be assume that the interviewees are not predominantly interested in the ACE or the festival, which began two weeks after the data collection. Indeed, only three participants stated that they visited the ACE exhibition before entering the café. Participants were asked whether they had heard about Geminoid HI-1 before. Twelve participants indicated that they had probably heard of Geminoid HI-1. But when the interviewer told them that Geminoid was the Asian man sitting in the café, they were utterly surprised and it was obvious they did not know beforehand what exactly the "Geminoid robot" is. Only two participants had been in the exhibition and read about it. One participant had been told beforehand by an acquaintance that there was a robot in the café. Thus, the probability is high that the majority of the participants was neither biased nor had had prior experiences with Geminoid.

3. Results

Statistical analyses were performed using IBM SPSS for Windows (Release 20.0; August 16, 2011; SPSS Inc. IBM, Chicago). Kolmogorov-Smirnov tests were calculated to test for normal distribution. For normal distributed data parametric tests like *ANOVAS* and *t* tests were used for further analysis. Data deviating significantly from normal distribution were subject to non-parametric tests. An alpha level of .05 was used for all statistical tests. In the following section the results of the interviews (section IV.3.1) and of the video analysis (section IV.3.2) will be reported in detail.

3.1 Interviews

To answer ***H1***, it was concluded from several open questions (see above) whether participants had recognized the robot or mistaken it for a human being. Of the 75 participants, 18 made no comments on this question (24%), because they had noticed neither the table nor the robot. They interpreted the questions as addressing the architecture of the café, which indicates that Geminoid HI-1 was not recognized as uncommon and did not become sufficiently salient for the participants. From the 57 participants (76%) who recognized the setting with Geminoid HI-1, 17 people mistook Geminoid HI-1 for a human being. Most of these participants did not believe that it was indeed a robot even after the experimenter had told them, and some announced that they would return for a second interaction. Forty participants clearly stated that they had seen a robot, although 20 of these mentioned that they had initially mistaken the robot for a human (cf. Table 8 for distribution of these statements across conditions).

Pearson's chi-square test was calculated and revealed a significant association between the manipulated condition (still, moving) and whether or not participants would recognize Geminoid HI-1 as a robot $\chi^2(2) = 8.075$, $p = .018$ (cf. Table 8). This seems to represent the fact that, based on the odds ratio, the odds of participants recognizing Geminoid HI-1 as a robot were 4.35 times higher when Geminoid HI-1 was displayed in the moving mode.

Table 8: Detection of Geminoid HI-1 as a robot

	still	**moving**	**TOTAL**
recognize Geminoid as…	***n***	***n***	***n***
a human being	10 (13%)	7 (10%)	17 (23%)
a robot or a puppet	10 (13%)	30 (40%)	40 (53 %)
Of those who recognized the robot, some stated that they had mistaken him for a human in the first instance.	*4*	*16*	*20*
did not recognize Geminoid HI-1 or the info table at all	10 (13%)	8 (11%)	18 (24%)
TOTAL	*30*	*45*	*75*

All percentages of total N=75

With regard to ***H2***, namely whether participants make uncanny valley-related statements, it was analyzed which reasons people gave for why they had recognized Geminoid HI-1 as a robot and whether they stated that they had experienced negative emotions. In order to avoid artificially prompting or suggesting experiences of uncanniness, there were no explicit questions regarding participants' possible (negative) emotional experiences with regard to the uncanny valley. However, results showed that only four participants mentioned unprompted that Geminoid HI-1 gave them an uneasy feeling (n=4; e.g.: "it looks so real, a little uncanny"; "I think that might be unpleasant" (to use Geminoid HI-1 for advertising)). When asked why they recognized that Geminoid HI-1 is not human, most participants referred to the stiff posture and abrupt movements (n=12, e.g.: "he sits there in a weird way"; "his movements are too jerky"; "I recognized no movement, the hands…"; "his restricted motor activity") or the lack of movements (n=2, e.g.: "We waved, but he didn't wave back."). Others mentioned that his face seemed like a mask (n=5) and his hands looked unnatural (n=8). Two mentioned that they recognized that the "man" sitting there was jacked up in some way (e.g.: "he was jacked up"; "I saw cables"). One participant initially concluded that Geminoid HI-1 might be a disabled person and two thought it was a wax figure. Some participants had difficulties in formulating their first impression of Geminoid HI-1 and eventually described it as a "kind of artificial being", "extraterrestrial", or just a "weird person". In sum, different aspects seemed to influence the participants' perception of Geminoid HI-1. As suggested by the uncanny valley theory, crucial factors were the movement as well as the unnatural hands and its unexpressive face.

With regard to the participants' interest in the robot, results show that among the forty participants who recognized Geminoid HI-1 as being a robot, twelve participants stated that they did not engage in longer interactions, because getting a coffee or something to eat was of higher priority than dealing with a robot. However, some suggested that they planned to go back and have a closer look later on.

3.2 Videos of interactions

According to ***RQ1***, different behaviors were analyzed, such as the time people appeared in the café, whether they performed actions to test the robot's capabilities, whether they spoke to Geminoid HI-1, and their nonverbal behavior (proximity to the robot, attention directed towards the robot).

3.2.1 Appearance time and testing actions

The amount of time for which people interacted with (or passed by) Geminoid HI-1 lay between 9.25 seconds and 277.44 seconds (M=48.17; SD=47.17). The high standard deviation shows how large the individual differences are in terms of the amount of time people spent in the café before they were asked to be interviewed. Some people quickly passed by the robot, whereas others spent several minutes exploring the robot's capabilities. A one-way ANOVA with the independent variable *condition* resulted in a main effect (cf. Table 9). Participants in the moving condition spend significantly more time in the part of the café where Geminid HI-1 was placed. A one-way ANOVA with the independent variable *detection of the robot* also resulted in a main effect (cp. Table 10). Participants who recognized Geminoid HI-1 as a robot spend significantly more time in the part of the café where Geminoid HI-1 was placed.

Table 9: Participants' appearance in seconds in dependence of the condition

	still	**moving**			
	M (SD)	*M (SD)*	*F*	*p*	η_p^2
appearance time	32.33 (19.94)	58.73 (56.52)	6.02	.017	.076

Table 10: Participants' appearance in seconds in dependence of whether participants recognized the robot

	recognized Geminoid HI-1 as…					
	…a human	**…a robot**	**…no statement**			
	M (SD)	*M (SD)*	*M (SD)*	*F*	*p*	η_p^2
appearance time	29.53 (11.25)	64.31 (58.83)	29.91 (17.71)	5.645	.005	.136
n=75	*n*=17	*n*=40	*n*=18			

Table 11: Distribution of testing actions for the moving condition (no actions in still condition)

	Touch	**Wave**	**Grimace**	**Tongue**	**Picture**	**Raise eyebrows**	**Talk to Geminoid**
moving	1	4	1	1	2	1	5

People tried different actions to test whether Geminoid HI-1 would react to them. Only one person touched the robot, although it could be observed that some accompanying persons touched Geminoid HI-1 while the interviewees watched or took a picture of the interaction. Four subjects waved (partially in front of Geminoid HI-1's face), one stuck out her tongue; one grimaced and two persons raised their eyebrows in an exaggerated manner. Two subjects took a picture or videotaped the interaction and five participants talked to Geminoid HI-1 (for the distribution across conditions, cf. Table 11). Interestingly, these actions by the participants to test Geminoid HI-1 were not performed in the *still condition*, but only in the *moving* *condition*. Moreover, all the participants who performed these actions stated that they recognized the robot as a robot, except one participant who seemed to be confused by the indirect questions and stated that she did not recognize the info table or anything special or unusual at all, but she observed the robot and waved to the robot.

3.2.2 Proximity

Regarding proximity, it was examined how close people came to Geminoid HI-1 and how long they stayed in the different proximity areas. Here, too, results showed great inter-individual differences, indicated by the high standard deviations over all proximity categories. The time spent within the “outer area” varied between 7.48 sec and 147.25 sec (M=27.98; SD=20.35). Most participants at least briefly went through the “vicinity area” and only three of the visitors chose a different path to cross the dining area to reach the bar. The remaining 72 participants were in the vicinity area for between 1.36 sec and 243.31 sec (M=12.25; SD=28.97). Seventeen subjects (22.6%) entered the “table area” and stood close to the table in front of the robot or surrounded the table to have a closer look at it. Subjects remained in the “table area” from 1.14 sec to 214.36 sec (M=9.27; SD=29.44). Only one person touched Geminoid HI-1. A one-factorial ANOVA with condition as independent variable and the proximity categories as dependent variables revealed no significant effects (for mean values cf. Table 12). A one-factorial ANOVA with the independent variable “detect Geminoid HI-1 as robot” and the proximity (vicinity area) as dependent variable revealed a significant effect which shows that people who recognized Geminoid HI-1 as a robot spent more time in the vicinity area (cf. Table 13).

Table 12: Time spent in the vicinity area in seconds in dependence of the condition

	still	**moving**
	M (SD)	*M (SD)*
Vicinity Area	5.13 (7.61)	16.99 (36.27)

Table 13: Time spent in the vicinity area in seconds in dependence of whether participants recognized the robot

	Recognized Geminoid HI-1 as…					
	…a human	**…a robot**	**…no statement**			
	M (SD)	*M (SD)*	*M (SD)*	F	p	η_p^2
Vicinity Area	2.92 (1.34)	20.10 (38.09)	3.58 (3.18)	3.359	.040	.085
n=75	n=17	n=40	n=18			

3.2.3 Participants' attention towards Geminoid HI-1

Participants' attention directed to the robot was coded as described above. By means of a one-factorial ANOVA, results showed that participants encountering Geminoid HI-1 in the *still condition* paid significantly less attention to the android than participants in the *moving condition* (cf. Table 14). Moreover, a one-factorial ANOVA with the independent variable "detect Geminoid HI-1 as robot" and the attention participants paid to the robot as dependent variables revealed a significant effect showing that people who recognized Geminoid HI-1 as a robot paid more attention to it (cf. Table 15).

Table 14: Participants' attention directed towards Geminoid HI-1 in seconds in dependence of the condition

	still	**moving**			
	M (SD)	*M (SD)*	*F*	*p*	η_p^2
Participants' attention	4.09 (7.90)	22.72 (35.65)	7.896	.006	.098

Table 15: Participants' attention directed towards Geminoid HI-1 in seconds in dependence of whether they recognized the robot

	Recognized Geminoid HI-1 as…					
	…a human	**…a robot**	**…no statement**			
	M (SD)	*M (SD)*	*M (SD)*	*F*	*p*	η_p^2
Participants' attention	2.81 (3.88)	25.87 (36.47)	3.45 (11.39)	6.389	.003	.151
n=75	*n*=17	*n*=40	*n*=18			

3.2.4 Speech

With regard to speech, it was analyzed whether or not people addressed Geminoid HI-1 verbally and how this behavior was distributed across conditions. None of the people in the *still condition* and 11% in the *moving condition* spoke to Geminoid HI-1 (cp. Table 5). Participants' utterances in the *moving condition* were quite short (three only said "hello", one said "I may take this [brochure], right?" and one said "I am going to take a picture, now. No! Please look up again").

3.2.5 Detection of the robot

From the interviews, it was already known that participants in the *moving condition* were more likely to recognize Geminoid HI-1 as a robot. Besides the actual manipulation of the experiment, there might be other factors influencing people's ability to recognize that

Geminoid HI-1 is a robot. It could be observed that some participants came alone to the café whereas others came in pairs or groups (participants' company). When people passed Geminoid HI-1, the robot was sometimes surrounded by other visitors and sometimes sitting there alone (group situation). Moreover, the eye contact Geminoid HI-1 established with participants and also the attention paid to Geminoid varied in length. All these factors might influence participants' ability to detect the robot as a robot. Thus, correlation analyses were calculated between *participants' ability to detect the robot* and the *Geminoid HI-1's eye contact with the participant, group situation* (Geminoid HI-1 is alone vs. Geminoid HI-1 is surrounded by visitors when subject arrives), *company* (subject is alone vs. in company), the length of *subject's attention paid to Geminoid HI-1*. There were positive correlations for *participants' ability to detect the robot* and *participants' attention paid to the robot* (r=.388, p=.001, n=75) and *Geminoid HI-1's eye contact with the participant* (r=.364, p=.001, n=75). In the following, it was examined whether both factors also predict participants' ability to recognize the robot and by conducting binary logistic regression analyses (Howell, 2010). Results showed that participants' attention paid to Geminoid was predictive. The more attention participants paid to the robot, the more easily people detected it as a robot (cf. Table 16). In addition, Geminoid HI-1's eye contact was predictive. The more eye contact the robot showed, the more easily people detected it as a robot (cf. Table 17).

Table 16: Logistic regression for detection of robot with the predictor participants' attention paid to Geminoid HI-1

		95% CI for Odds Ratio		
	B (SE)	Lower	Odds Ratio	Upper
Included				
Constant	-.806 (.32)			
Participants' attention	.118* (.03)	1.04	1.125	1.21

Note: R^2=.35 (Hosmer & Lemeshow); .28 (Cox & Snell), .36 (Nagelkerke). Model $x^2(1)$ =24.14, p < .001. *p<.01*

Table 17: Logistic regression for detection of robot with the predictor Geminoid HI-1's eye contact

		95% CI for Odds Ratio		
	B (SE)	Lower	Odds Ratio	Upper
Included				
Constant	-.494 (.29)			
Geminoid HI-1's Eye Contact	.048* (.02)	1.01	1.049	1.08

Note: R^2=.14 (Hosmer & Lemeshow); .18 (Cox & Snell), .24 (Nagelkerke). Model $x^2(1)$ =14.86, p < .001. *p<.01*

It could be assumed that this effect was mediated by the time people spent in the vicinity area. And indeed, the relationship between Geminoid HI-1's eye contact and the participants' ability to detect that Geminoid HI-1 is a robot was fully mediated by the time they spent in the vicinity area. As Figure 22 illustrates, the standardized regression coefficient between Geminoid HI-1's eye contact and detection decreased substantially when controlling for the time spent in the vicinity area. The other conditions of mediation were also met: Geminoid HI-1's eye contact was a significant predictor of the participants' ability to detect that Geminoid HI-1 is a robot (cf. Table 17) and of the time spent in the vicinity area (β=.71, $t(88)$ =9.53, $p < .001$, and also explained a significant proportion of variance, R^2=.51, $F(1,90)$=90.81, $p < .001$) . The time spent in the vicinity area was a significant predictor of the participants' ability to detect that Geminoid HI-1 is a robot while controlling for Geminoid HI-1's eye contact (cf. Table 18).

Table 18: Logistic regression for detection of robot with the predictor proximity (vicinity area)

		95% CI for Odds Ratio		
	B (SE)	Lower	Odds Ratio	Upper
Included				
Constant	-1.086 (.32)			
Proximity	.07* (.02)	1.03	1.07	1.12

Note: R^2=.21 (Hosmer & Lemeshow); .21 (Cox & Snell), .29 (Nagelkerke). Model $x^2(1)$ =21.09, $p < .001$. **p<.01*

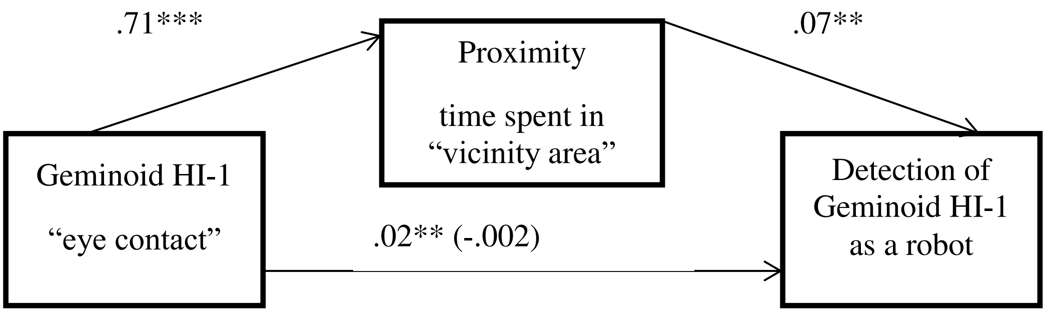


Figure 22: Mediated regression analysis

Standardized regression coefficients for the relationship between Geminoid HI-1's eye contact and the participants' ability to detect that Geminoid HI-1 is a robot as mediated by the time spent in the vicinity area (proximity). The standardized regression coefficient between Geminoid HI-1's eye contact and the detection of Geminoid HI-1 as a robot controlling for time spent in vicinity area is in parentheses. *p<.05, **p<.01, ***p<.001.

3.2.6 Participants meeting Prof. Ishiguro

Of the seven participants who met Prof. Ishiguro, five reported that they had noticed a (human) man behind the table and the remaining two did not notice anything special at all. Prof. Ishiguro established eye contact with all of the participants (M=29.96 seconds; SD=49.43). However, participants' eye contact was rather short (M=8.35; SD=13.71). One older couple stood in the (or next to the) table area looking at the brochures and asking Prof. Ishiguro briefly whether they were allowed to take one. All other participants did not engage in interactions and just passed by.

4. Discussion

The study aimed to open up a new perspective on the investigation of human-robot interaction with android robots in the field. Thus, this observational field study presented data of unprompted and unscripted interactions between humans and the android robot Geminoid HI-1 in an Austrian café. Ninety-eight participants were invited to take part in an interview and their interactions with Geminoid HI-1 were analyzed with regard to the following dimensions: the appearance time, proximity to the robot, attention paid to the robot, actions to test the robot's capabilities and verbal addressing of the robot.

Unlike previous research investigating human-robot interactions with androids in laboratory settings or in field trials, in which the investigative nature of the study was obvious to the participants (Becker-Asano et al., 2010; Straub et al., 2010), participants in this study would not expect to encounter a robot. There were no hints that they would interact with an android robot and the interactions did not follow any script. Given this very free situational context, this study explored whether people would recognize the android as a robot and whether this is mediated by different degrees of displayed behavior. Results show that thirty-five participants either mistook Geminoid HI-1 for a human, or even did not notice it at all, because it did not seem to appear conspicuously non-human. This effect was mediated by the displayed behavior of the android. People in the moving condition were able to most reliably tell that Geminoid HI-1 was a robot, which might be caused by the rather jerky movements of looking up from the table to the participant or re-directing the attention to another participant. The effect was fully mediated by the time people spent in the direct area around Geminoid HI-1. This means that Geminoid HI-1's eye contact caused people to spend more time in its adjacency and thus they clearly also had more time to explore the robot's capabilities. This result confirmed the assumption based on the results of Study 1 that the android's behavior serves as cue to more easily categorize the robot as such.

When subjects became aware of the robot, they took a closer look and some explored Geminoid HI-1's capabilities. Only in the moving condition, participants tested Geminoid HI-1's capabilities by waving their hands in front of its face, saying hello to it, making a grimace or sticking out their tongue in anticipation of an appropriate reaction. Interestingly, these actions were not performed in the *still condition* (also not in the condition with Prof. Ishiguro). This might be due to the fact that people also spent less time in front of Geminoid HI-1 when it did not react at all to the participants. This is in line with the answers to the question of why participants recognized that Geminoid HI-1 is not human given that most participants referred to the stiff posture and abrupt movements. Participants who encountered Geminoid HI-1 in the *still condition* were only able to see very subtle movements (blinking, breathing), if any at all and therefore did not perceive this cue. Two participants mentioned that they recognized that the "man" sitting there was jacked up in some way. Participants in both conditions also mentioned other reasons for why they detected the robotic nature of the Asian "man", for instance the lack of movement, its unexpressive face, the clumsy hands or its skin.

With regard to the uncanny valley effect, it was assessed whether people reported unprompted about (negative) feelings regarded as being related to the uncanny valley effect such as distress, fear or disgust. In contrast to Becker-Asano et al. (2010), who showed that around 37% of the participants mentioned emotional terms related to fear and disgust, participants in the present study reported less negative feelings in the interviews. Only three people (4%) mentioned that Geminoid HI-1 gave them an uneasy feeling. There are two explanations for this lack of negative feelings. First, the participants' feelings were not explicitly asked for and so they might have held back with this information, because they did not regard this as important or appropriate to be mentioned during the interview. The second explanation could be that the majority of the participants either did not experience negative feelings, or these negative feelings were only short-term and were not reported during the interview, because the feeling had already vanished or had been resolved during and after the interaction with the robot.

Against the background of Ramey's (2006) thoughts on the uncanny valley and his theory that it is difficult to categorize robots into either "alive" or "not alive", it is very interesting that some participants indeed did not instantly describe Geminoid HI-1 as either a human being or a robot. They rather described their first impressions with words indicating their difficulties in categorizing the robot, e.g. "kind of artificial being" or "extraterrestrial". Others described the robot with terms like “disabled person” or “weird person” indicating that they predominantly had the impression of a human being, but recognized something that did not fit into the stereotype of a healthy man. This is in line with the findings of Straub et al. (2010), who found that Geminoid HI-1 was perceived as an entity “in-between”. However, with regard to the participants’ behavior, results showed that those participants who noticed that Geminoid HI-1 was a robot showed interest rather than negative reactions. In general, the behavioral data show that although Geminoid HI-1 was deemed to fall into the uncanny valley, people were rather relaxed when meeting it in public in this unscripted situation.

Based on related work showing inter-individual differences in human-robot interaction (Hayashi et al., 2007; Kanda et al., 2007; Shiomi et al., 2007; Sung et al. 2009; Sung et al., 2010; von der Pütten et al., 2011; Weiss et al., 2010), it has been assumed that people would show huge inter-individual differences in their behavior. Indeed, results showed inter-individual differences with regard to all categories, as indicated by the high standard deviations for the coded behaviors: appearance time, attention and proximity. When considering the factor of whether people recognized Geminoid HI-1 as a robot, it was shown that for people who failed to recognize him, appearance time was shorter as well as the fact that they paid less attention to the robot and spent less time in the vicinity area. For these people the behavior was quite homogeneous as indicated by small standard deviations. For people recognizing the robot as such, appearance time, attention and the time spent in the vicinity area on average were much higher. But the standard deviations indicate that these people showed very different behavior. With regard to the occurrence of testing actions, it was shown that some people tried very different methods to test the robot’s capabilities, while others merely observed the scenery.

Furthermore, an interesting finding is that there were also a lot of participants (about 15%) who virtually ignored the robot and quickly passed by. Although stating in the interviews that they recognized it as being a robot, they decided that getting a coffee was of higher priority than exploring it. This suggests that for a certain amount of people, robots (at least of this type) did not seem to be of high interest. At least in the given situation, they seemed not to care about them being around and proceeded with their planned activities. This corresponds to the findings of Hayashi et al. (2007). In their field study with robots in a railway station, people were found to differ in the amount of interest shown in the robots depending on the time of day and the day of the week. For example, during rush hour, people showed less interest, presumably because they wanted to get to work on time. It is noteworthy that the participants in this present study were not predominantly visitors to the Ars Electronica Center, but rather tourists and locals who visit the café frequently because of its good cuisine. Only three participants stated that they had visited the AEC before they entered the café. It can be assumed that the majority of our participants were not particularly interested in robots. Therefore, further studies should control for the general interest in robots by, for instance, including corresponding questions in their post-experimental questionnaires.

5. Limitations

The quasi-experimental setting of this study was accompanied by several problems. The sample was dependent on the visitors to the café agreeing to take part in the interviews. This caused an uneven distribution over the conditions, because, for instance, fewer people happened to agree to participate on the days when we installed the *still* set-up. Only those participants who agreed to engage in interviews were included in the video evaluation and this might have skewed the results. When regarding for instance the touching of the robot, it could be observed that in some cases the participant who agreed to be interviewed did not touch the robot, while the person accompanying the participants touched it. However, the participants' companions were not included unless they agreed in the interviews and video analysis, because the goal was to combine both measures. For future analyses it would be very interesting to analyze the interactions of all persons interacting with Geminoid HI-1 regardless of whether they took part in the interviews. Moreover, the data could be qualitatively analyzed using interaction analysis and conversation analysis techniques. With regard to the data analysis of the participants' nonverbal behavior, the analysis in this study was restricted to those behaviors that were easily observable in the videos. Although other studies showed that smiling is also an important nonverbal behavior to investigate (von der Pütten et al., 2011) the quality of the video material did not allow the coding of smiling behavior.

Furthermore, it was only possible to draw implicit conclusions with regard to the uncanny valley, because the questionnaire did not contain specific questions asking, for example, participants about their feelings while encountering the robot. During the interviews the experimenters did not want to prompt people on the possible uncanniness of the robot in order to avoid participants responding in a socially desirable way. However, future studies examining the uncanny valley effect in a similar setting could include interview questions asking for the participants' feelings and their general attitudes towards the robot. Like the results of other field and laboratory studies, the results apply for the robot used in this study, the android robot Geminoid HI-1, and might not be generalizable for other android robots.

V. STUDY 3: ONLINE SURVEY ON ROBOT APPEARANCES

1. Introduction

According to the uncanny valley hypothesis two key factors contribute to uncanny valley related responses, namely human-likeness and movement. While Study 2 focused on the key factor movement, this third study will examine the other key factor, human-likeness. As already mentioned in section II.2, the translation of Mori's dimensions has long been controversial. The x-axis was interpreted as the dimension of human-likeness or sometimes as the dimension of anthropomorphism (Bartneck et al., 2009). However, researchers using both translations refer to the fact that increasing human-likeness or anthropomorphism is characterized by closer resemblance to human appearance. In this context, it can be assumed that androids might elicit the same evaluation processes as humans with regard to judging their appearance. However, there is no general agreement on what is beautiful when it comes to non-android robots which will be examined in this third study. The following sections will review briefly studies that directly investigated robot appearances (section V.1.1) and studies investigating the uncanny valley that are to some extent related to the factor appearance (section V.1.2.). Section V.1.2 also addresses methodological issues in uncanny valley research. Section V.1.3 will summarize participant inherent factors influencing the perception and evaluation of robots and finally the research questions and hypotheses are presented in section V.1.4.

1.1 Empirical results regarding robot appearances

As already exemplified in the literature review, the uncanny valley has been researched not only by scholars in the field of robotics, but also of those in the field of virtual characters. With regard to virtual faces, it has been shown that the same principles for judging the attractiveness of humans also hold for the judgment of attractiveness for virtual agents (Sobieraj, 2012). Here, the finding, ''what is beautiful is good'' (Dion et al., 1972), in the sense that attractive people are also rated positively in other aspects holds true also for virtual agents as well. It can be assumed that especially android robots will underlie the same principles for judging attractiveness, because they expose a closely human-like appearance. The results of Study 1 (reported and discussed in section III) seem to reflect this assumption. Participants seemed to apply the same rules of attractiveness to the android robots as they do to humans. Accordingly, HRP-4c was perceived as attractive and likable, while CB2 and Geminoid HI-1 were evaluated negatively. However, there is still little known on what exactly is perceived as beautiful when it comes to robots which are not android.

A number of studies addressed the aspect of appearance as already presented in section II.4.4. For instance, DiSalvo, Gemperle, Forlizzi, and Kiesler (2002) found that the more features a robot head possesses (e.g. existence of eyes, nose etc.) the more human-like it was perceived to be. Moreover, the width/height ratio of the head was important, because the wider the head in relation to its height (in other words the more squared and not rectangle the head was), the less human-like it was perceived. DiSalvo et al. also found that the presence of a nose, eye-lids and a mouth were of great importance for human-likeness ratings. Power and Kiesler (Powers & Kiesler) varied chin length and forehead height as well as the voice in videos of robotic talking heads. They found that a shorter chin made the eyes a larger proportion of the face. Since this design falls under the baby-scheme, they discuss that their participants followed the recommendations of a baby-faced robot rather than those of a non-baby-faced robot, because also baby-faced men were generally perceived to be more honest, kind, and warm. However, the findings of DiSalvo et al. and Powers and Kiesler are limited to heads of humanoid robots and do not examine effects for non-humanoid robots or robotic bodies. Participants answers in the qualitative interviews in Study 1 revealed that some parts of the robots' bodies (e.g. face, eyes, hands, and voice) were important for some participants with regard to likability ratings, but there was no general agreement among all participants as to whether a robot should feature these aspects of appearance or not.

Results of different studies demonstrated that expected cognitive capabilities of a robot and its expected behavior are linked to the appearance of this robot (e.g. Gray & Wegner, 2012; Hegel et al., 2008; Hegel et al., 2008; Krach et al., 2008; Woods, 2006). The qualitative interviews revealed similar tendencies. For instance, participants generated expectations about a robot's movement based on the pictures they saw. Very human-like robots elicited higher expectations in terms of smoothness and velocity and with regard to lifelikeness in general. Moreover, the cinema question led some participants to think about the robots' cognitive abilities. For some robots they were more likely to believe that the robots would actually understand and experience a movie, while others were denied this ability.

Goetz, Kiesler, and Powers (2003) found that people preferred robots for jobs when the robot's human-likeness matched the sociability required in those jobs. A similar finding appeared in the results of the qualitative interviews in Study 1. Although participants appreciated android robots as a demonstration of technological advancement, the resemblance to humans was perceived as unnecessary and participants preferred functionality. Moreover, the appearance was expected to match the functionality. There were also some indicators for design preferences for non-android robots. For instance, participants liked sleek designs in contrast to too bulky ones or robots that look "unfinished". Moreover, more communicative robots were seen in more communicative jobs.

A lot of experiments examine the importance of appearance by comparing two different robots (e.g., Carpenter et al., 2009; Chee et al., 2012; Hinds et al., 2004; Kanda et al., 2008; Komatsu & Yamada, 2007; Li et al., 2010; Lohse et al., 2007; Robins et al., 2004). For instance, Kanda et al. (2008) compared how people react towards the robots Robovie, ASIMO and a human control interaction partner. These two robots, however, are very different in many ways, e.g. they differ with regard to color, body form (bi-pedal versus wheeled robot), and facial features and in the overall design (ASIMO looks more sleek and finished than Robovie). Thus, it is hard to say which component of appearance is responsible for the effect on participants' behavior. Similar experiments prove the importance of appearance as they show that appearance frequently influences users' evaluations of and behavior towards robots, but suffer from the same problem; that is that effects are hard to attribute to specific aspects of appearance.

From the interview results from Study 1 it can be assumed that the robots' height seems to contribute to the perception of possible danger, because several participants pointed out that they were less afraid of a not nice-looking robot, when they discovered that it was rather small.

1.2 Appearance and the uncanny valley

With regard to testing the uncanny valley hypothesis by emulating Mori's proposed graph a number of studies have been conducted. The studies differed in the approaches showing an uncanny valley effect. They used different stimulus material (e.g. morphed pictures; pictures of actual humans, robots and computer graphics; videos of actual robots) which was often rather limited and not standardized (e.g. Bartneck et al., 2007; MacDorman, 2006; Riek et al., 2009). Also these studies did not focus on the question of which characteristics of appearance contribute to a positive or negative perception, but rather tried to show that there are indeed uncanny valley responses. Thus, conclusions on the impact of appearance are only implicit and merely show that changes in appearance (be they gradual as in morphed pictures or rather distinct as in videos of actual robots) result in different perceptions. Moreover, these studies first and foremost included only a few relevant items in the evaluations of the robots (e.g. “How uncanny / familiar / human-like is the robot?”; e.g., Hanson et al., 2005; Hanson, 2006; Lay, 2006; MacDorman & Ishiguro, 2006; Riek et al., 2009; Tinwell & Grimshaw, 2009; cf. discussion in section II.4.1). This can be problematic since familiarity and human-likeness or anthropomorphism can be understood as complex phenomena which might not be adequately accounted for by using just one item, but there were no standardized measurements for evaluating robots or human-robot interactions when these studies were conducted. However, Bartneck, Kulić, Croft, and Zoghbi (2009) developed a questionnaire to evaluate human-robot interactions based on five key concepts (anthropomorphism, animacy, likeability, perceived intelligence, perceived safety) identified after literature review on human-robot interaction evaluation studies. Each key concept is addressed with one set of items. This questionnaire was not developed specifically to investigate the uncanny valley, but to evaluate human-robot interactions in general. The authors used semantic differentials, because semantic differentials are known to effectively reduce acquiescence bias without lowering psychometric quality. Moreover, they felt vindicated in using semantic differentials instead of Likert-scales because “Powers and Kiesler [16] report a negative correlation (−.23) between “Human-likeness” and “Machine-likeness”, which strengthens our view that semantic differentials are a useful tool for measuring the users’ perception of robots, while we remain aware of the fact that every method has its limitations.” (Bartneck et al., 2009, p. 73). Besides the fact that this is a rather weak correlation it has to be noted that in the study by Powers and Kiesler (2006) only one type of robot was evaluated and that there might be other cases where a robot can receive high or low ratings on both scales. In using semantic differentials this possibility will be excluded, because participants have to decide on just one dimension - whether the robot is human- or machine-like. The results of the interviews in Study 1 suggest that robots can be simultaneously perceived as mechanical and human-like. Bartneck et al.’s “Godspeed Questionnaires” are a rather general measurement tool for evaluating human-robot interactions and were not especially developed to investigate the uncanny valley hypothesis. In this regard, Ho and MacDorman (2010) criticized that the Godspeed questionnaires are unsuitable for examining uncanny valley related responses. They discuss that Mori’s term shinwa-kan may best be translated with likability in the sense of interpersonal warmth, but that Mori’s terminology for negative shinwa-kan, “bukimi”, is best translated with eeriness, which could hardly be seen as the opposite anchor of warmth. They conclude that “shinwakan and bukimi appear to constitute distinct dimensions” (Ho & MacDorman, 2010, p. 1508), which should be measured separately. However, the Godspeed Questionnaire does not include a measure for eeriness. Moreover, Ho and MacDorman criticize that the five Godspeed indices are not decorrelated from positive or negative affect, because the adjectives used to form the semantic differentials have a positive (e.g. natural, moving elegantly) versus negative (e.g. fake, moving rigidly) connotation. Moreover, the five concepts are not decoupled from each other and share, for instance, the same items. Thus, Ho and MacDorman developed a new set of indices (Humanness, Attractiveness, Eeriness) with the aim of keeping humanness free of positive or negative connotations in order to have concepts that present purely the x-axis (humanness) and y-axis (eeriness, attractiveness) and decouple them from a separate index on affect (interpersonal warmth). Interestingly, the authors were able to produce scales for eeriness and attractiveness that were decoupled from warmth. This was, however, not possible for the humanness scale indicating "that the notion of warmth might strongly overlap with the concept of humanness in practical circumstances. It is difficult to obtain discriminant validity; however, this may be improved in future studies." (Ho & MacDorman, 2010, p. 1515). Another interesting issue is that the humanness scale refers solely to the life-cycle of humans and biological characteristics (mechanical versus biological movement, synthetic versus real, artificial versus natural, without definite lifespan versus mortal). This is in contrast to the general agreement that the human-likeness dimension in Mori's graph refers, first and foremost, to the resemblance to humans with regard to appearance and might also explain the lack of discriminant validity. The items in the humanness scale refer more explicitly to characteristics distinguishing humans from robots, hence making the in-group of humans more obvious. Since we tend to rate in-group members more positively than out-group members, this might be an explanation why humanness ratings were so strongly correlated with positive affect (interpersonal warmth). Although the Godspeed Questionnaires have been used frequently to evaluate human-robot interactions, in the context of the uncanny valley researchers focus more on the usage of a limited set of uncanny valley related items and on objective measurements.

Most previous studies trying to show, describe, and explain the uncanny valley effect used a common procedure to probe for the uncanny valley function, that is, plotting ratings for uncanniness or eeriness against ratings for human-likeness. Results were often presented in a more descriptive nature (e.g., Hanson, 2006; Hanson et al., 2005; Lay, 2006; MacDorman, 2006; MacDorman & Ishiguro, 2006; MacDorman et al., 2009; Tinwell & Grimshaw, 2009). However, Burleigh et al. (2013) summarized that "the theory predicts a nonlinear relationship between human-likeness and emotional response" and therefore tested whether linear, quadratic or cubic models fitted best to their four data sets and found that in contrast to Mori's hypothesis linear models fitted best for all four stimuli which were morphed pictures with gradual changes in prototypicality and geometric realism. In a follow up study, looking into feature atypicality, variations in category membership and texture realism as causes for the uncanny valley effect, Burleigh et al. again test which model fitted to the data best. Again they observed a linear relationship for the continuum with different skin coloration. However, the data for the continuum addressing category membership could not be explained by a linear function although a linear trend was observable in the plot. There were outliers in the middle between the two extremes which support the author's hypothesis that conflict of categories elicits a negative response leading to Mori's assumed non-linear curve. Burleigh et al. conclude that their results "might be accounted for on the basis of the stimulus belonging simultaneously to multiple ontological categories, which elicits a state of discomfort because it is ambiguous and conflicting" (Burleigh et al., 2013, p. 770). Moreover, they assume that also the results of previous studies could be explained by this, because in most studies different categories were merged (e.g. robots and humans in MacDorman & Ishiguro, 2006; Mitchell et al., 2011; Saygin et al., 2012; or dolls and humans in Seyama & Nagayama, 2007). However, this does not explain the failures to produce an uncanny valley effect although merging different categories (e.g. Hanson, 2006; Hanson et al., 2005). In conclusion, the approach of Burleigh et al. (2013) to not only plot their data in order to perform a visual inspection of whether Mori's graph could be reproduced, but to abstract which kind of mathematical function should explain the data in order to fit into Mori's hypothesis is promising to substantially contribute to the debate.

1.3 Factors influencing the perception of robots

Not only appearance characteristics of the robots will elicit differences in evaluations. Studies have shown the influence of characteristics which are on the participants side. For instance Schermerhorn et al. (2008) found that women evaluate robots differently from men. Syrdal, Koay, Walters and Dautenhahn (2007) found differences with regard to which approach direction was preferred by participants, based on gender and personality traits such as extraversion. Similarly, Nomura, Kanda, Suzuki and Kato (2008) reported diverse gender differences in relation to participants' dispositional anxiety towards robots with regard to, for instance, their approaching behavior in human-robot interaction. Of special interest is also participants' general attitude towards robots. Nomura, Suzuki, Kanda and Kato (2007) developed a scale for measuring anxiety towards robots and found in subsequent experiments a relationship between negative attitudes and participants behavior in human-robot interaction scenarios (Nomura et al., 2008). In conclusion, there are a number of factors influencing how robots may be perceived and evaluated by humans. The effects, however, are not consistent.

1.4 Research questions and hypotheses

With regard to previous work on the appearance of robots and which aspects are perceived as positive or negative, there is only limited systematic research. The studies focussing on the uncanny valley effect often used non-standardized picture and video material or morphed pictures. But even more important, they were not designed to reach conclusions about the actual appearance, but rather aimed at emulating the uncanny valley graph. Those studies systematically investigating robot appearances (e.g. DiSalvo et al., 2002; Powers & Kiesler) are limited to the heads of humanoid robots neglecting non-humanoid robots and the robots' bodies. The results from the interviews indicated that the android robots were judged using the same rules as those for humans as could also be assumed regarding findings with regard to the perception of virtual agents (Sobieraj, 2012). There were also some indications of which aspects of appearance were important with regard to the likability of the robots (e.g. face, eyes, and hands). However, there was a limitation in that only humanoid and android robots were included as stimuli leaving out mechanical robots. Moreover, actual available robots feature very different designs so that other aspects of appearance besides being android or not such as color and shape, might elicit different evaluations. Further, the interviews only gave first qualitative insights into how humanoid and android robots were perceived with regard to a variety of aspects and the results cannot be generalized.

Therefore, a new approach will be used in the following two studies, an online survey with a large set of actual available robots, and a laboratory experiment using an affective priming paradigm.

In the first part of this third study a large set of pictures of actual available robots will be evaluated using items which are related to traditional scales used in research on person perception (e.g. likable, attractive) and those items relevant for the uncanny valley phenomenon (e.g. uncanny, eerie, human-like, familiar). Using pattern recognition techniques this set of robots will be examined to identify clusters of robots which are evaluated similarly on specific variables. The resulting clusters will be examined with regard to characteristics of appearance which are shared among the robots in the specific cluster. The according research question is:

RQ1: By means of which dimensions are clusters of robots identifiable and what design characteristics do robots in one cluster share?

RQ2: How are the robots in these clusters evaluated?

Since the interview results suggest that robots can have both mechanical and human-like features, mechanical and human-like will not be used in a semantic differential (e.g. Bartneck et al., 2009; Ho & MacDorman, 2010), but as separate items, to examine whether there are negative correlations for all robots in the sample as they were found in a previous study (Powers & Kiesler, 2006). The according research hypothesis is:

H1: Ratings for human-likeness and mechanicalness are negatively correlated for all robots.

According to the uncanny valley hypothesis there is a relationship between the robots human-likeness or their mechanicalness, respectively, and participants' responses towards these robots. The theory assumes that increasing human-likeness is the cause for participants' responses. Thus it can be hypothesized that

H2: Human-likeness is a predictor for participants' evaluations of the robots.

H3: Mechanicalness is a predictor for participants' evaluations of the robots.

Furthermore, Burleigh et al.'s approach will be used to explore which mathematical function best predicts the obtained data in order to draw conclusions on the meaningfulness of the uncanny valley graph. Mori's graph is obviously based on a cubic function. According to the thoughts of Bartneck et al. (Bartneck et al., 2007) there might be an uncanny cliff instead of an uncanny valley (cf. section II.3.4) which would resemble a quadratic function. The simplest relationship would be a linear relationship. Accordingly, it is asked:

RQ3: Which mathematical function (linear, quadratic, cubic) best fits the obtained data?

Moreover, diverse factors have been shown to be influential with regard to the perception and evaluation of robots, like participants' gender and personality traits such as extraversion. Moreover, previous research suggests that increased robot anxiety will lead to a more negative evaluation of robots. Thus the following hypotheses are proposed:

RQ4: Does the gender of the participants, their personality and/or their interest in technology influence the overall evaluation of the robots?

H4: Robot anxiety influences the overall evaluation of robots negatively.

In a follow-up study (Study 3b) robots from the derived clusters will be used in an affective priming paradigm (Fazio, Sanbonmatsu, Powell & Kardes, 1986; Fazio, 2001) to gather data on implicit attitudes towards these robots. For more details see section V.3.

2. Study 3a – Online survey on robot appearances

In this first part of the third study (Study 3a), actual available robots will be evaluated with regard to person perception and uncanny valley related items in an online survey.

2.2 Method

In section V.2.2.1 the stimulus material of the online survey will be described in detail, followed by a description of the measurements (section V.2.2.2), explanatory variables (section V.2.2.3), sample (section V.2.2.4) and procedure (section V.2.2.5).

2.2.1 Stimulus material

As stimuli standardized pictures of 40 robots were used. Most of these robots are research objects and thus not known among the public. Moreover, the robots vary in size, color and design, e.g. some have wheels and some are bi-pedal. This was to guarantee that the stimulus material has enough variance. The robots included in this study are: Aisoy, Armar-III, Asimo, Atom, Autom, Cosmobot, Dynamoid, Geminoid HI-1, Geminoid DK, Hwarang, HRP2, HRP3, HRP-C4, Justin, IbnSina, ICat, Kismet, Kobian, Leonardo, Lucas, Luna, Mika, Nao, Olivia, Papero, Phope, Popo, Pr2, REEM1, REEM1390, Riba, Ri-Man, Robosapien, Robovie-mR2, Robonova, EMYS, Snackbot, Twendy-one, Wabian, and Wakamaru. The pictures showed the full-sized robot in front of a white background. When possible, pictures were taken frontally in a still posture without movement or facial expressions (cf. Figures 24-28 for pictures of the robots). Each robot was presented on a separate page of the questionnaire (see Appendix B) alongside its actual height (above the picture) and the items which will be described in more detail in the following. Participants were randomly assigned to one of four questionnaire sets displaying the robots in different orders to avoid sequence effects.

2.2.2 Measurements

First, participants' perceptions of the robots in terms of person perception were assessed. For this purpose 16 items were chosen in accordance with uncanny valley related concepts: positive affect in terms of how likable the robot is perceived to be (items: likable, pleasant, attractive, natural), familiarity of the robot (items: familiar, unfamiliar, strange), negative affect in terms of perceived dangerousness of the robot (items: dominant, submissive, weak, harmless, threatening), negative effect in terms of perceived uncanniness of the robot (items: uncanny, eerie) and perceived intelligence of the robot (items: intelligent, incompetent).

Participants rated each robot with regard to these 16 items on a 5-point Likert Scale from “I agree” to “I do not agree at all”.

The ratings for all 40 robots by all 151 participants (with some missing ratings for single robots resulting in N=6033 cases) were used in an exploratory factor analysis (EFA) to expose underlying latent variables behind the 16 items. The Kaiser-Meyer-Olkin (Kaiser, 1974) measure verified the sampling adequacy for the analysis, KMO = .86 (“great” according to Hutcheson & Sofroniou, 1999), and all KMO values for individual items were >.68, which is well above the acceptable limit of .5 (Field, 2009). Bartlett’s test of sphericity (Bartlett, 1937) χ^2 (120) = 47404.82, p <.001, indicated that correlations between items were sufficiently large for EFA. Four components had eigenvalues over Kaiser’s criterion of 1 (Kaiser & Dickman, 1959) and in combination explained 69.18% of variance. The scree test (Cattell, 1966) also showed an inflexion that would justify retaining four components. However, since Kaiser’s criterion and scree test are affected with the risk of overfactoring (Ferguson & Cox, 1993) in addition parallel analysis according to Horn (1965) was conducted to verify the extraction of four factors. During parallel analysis those factors were identified whose empirical eigenvalues based on the sampling data were higher than the eigenvalues that can be expected to be obtained from completely random data. Results also suggested the extraction of four factors. Table 19 shows the empirical and calculated eigenvalues according to the parallel analysis. Given that all three methods for factor extraction indicated four components, this was the number of components that were retained in the final analysis. Principal component analysis (PCA) was chosen as extraction algorithm as recommended by Ferguson and Cox (1993) with varimax rotation as rotation method. PCA resulted in four factors. Factor loadings and communalities are displayed in the component matrix in Table 20.

Table 19: Empirical eigenvalues of the PCA (with varimax rotation) of the robot perception ratings (16 items) compared with eigenvalues obtained by parallel analysis (Horn, 1965)

Factor	**Eigenvalue (empirical)**	**Eigenvalue (parallel analysis)**	**Variance in %**	**Cumulative Variance in %**
1	**0.80**	**4.79**	29.96	29.96
2	**0.82**	**2.98**	18.62	48.58
3	**0.85**	**2.19**	13.67	62.25
4	**0.87**	**1.11**	6.93	69.18
5	0.89	0.69	4.29	73.47
6	0.92	0.58	3.64	77.11
7	0.95	0.53	3.31	80.42
8	0.99	0.49	3.09	83.51
9	1.03	0.45	2.83	86.34
10	1.09	0.43	2.68	89.01

Table 20: Summary of items, factor loadings and communalities for varimax four-factor solution for the perception of the robots (N=6033)

items	factor loading				communality
	factor 1 threatening	**factor 2 likable**	**factor 3 submissive**	**factor 4 unfamiliar**	
threatening	**.886**	-.087	-.061	.129	.580
eerie	**.879**	-.057	-.015	.123	.650
uncanny	**.827**	-.083	.077	.191	.697
dominant	**.737**	.128	-.349	.128	.722
harmless (rev)	**-.539**	.475	.380	.157	.733
pleasant	-.259	**.817**	.084	-.004	.741
likable	-.268	**.801**	.091	-.003	.813
attractive	.041	**.762**	.009	-.107	.637
familiar	-.010	**.747**	.148	-.336	.706
natural	.246	**.653**	.058	-.383	.594
intelligent	.207	**.560**	-.523	.296	.791
incompetent	.168	.025	**.820**	.061	.693
weak	-.308	.207	**.618**	.246	.615
submissive	-.356	.323	**.567**	.250	.697
strange	.222	-.176	.141	**.773**	.718
unfamiliar	.232	-.156	.139	**.743**	.684
eigenvalue	4.79	2.98	2.19	1.11	
% of variance	29.96	18.62%	13.67%	6.93%	
Cronbach's α	.886	.827	.653	.674	

Principal component analysis with varimax rotation and Kaiser normalization
Note: Boldface indicates highest factor loadings

PCA showed satisfying factor loadings (>.400; cf. Stevens, 2009; Velicer, Peacock, & Jackson, 1982) for all variables, but also cross loadings for the two items, harmless and intelligent, indicating that these items are related to more than one variable. Harmless showed conceptual overlap between factor one, two and three. Intelligent showed conceptual overlap between factors two and three. Both items are theoretically important for the research question, because they reflect how the robots are perceived with regard to likability and eeriness which are the positive and negative valence of affinity which marks the y-axis of the uncanny valley graph. Given the limited number of variables and the theoretical importance of the items with regard to the research question, it was decided to retain the items harmless and intelligent within the analysis in spite of their cross loadings. Thus, the four resulting factors of the PCA are:

1) *threatening* with the items threatening, eerie, uncanny, dominant, and harmless (reverse)

1) *likable* with the items pleasant, likable, attractive, familiar, natural, and intelligent

3) *submissive* with the items incompetent, weak, and submissive

4) *unfamiliar* with the items strange, and unfamiliar

The factors *threatening* and *likable* showed high reliabilities of Cronbach's α of .886 and .827 (Cronbach, 1951). However, the factors *submissive* and *unfamiliar* had relatively low reliabilities with Cronbach's α of .653 and .674. General rules suggest using subscales with Cronbach's alphas of at least .70 (c.f. Kline, 1999). However, Cortina (1993) discussed that a low number of items can artificially deflate alpha values. Moreover, both factors are concerned with key concepts with regard to the research question. Thus, the factors *submissive* and *unfamiliar* will be used for further analysis, but results will be interpreted with caution.

Besides the sixteen items on person perception, participants were asked as how human-like and how mechanical, respectively, participants perceived the robots to be on a 5-point Likert-Scale ("not at all human-like/mechanical" to "very human-like /mechanical"). The adjectives were assessed as two separate items and not as semantic differential, in order to examine whether they correlate.

Moreover, participants were asked whether they noticed a specific positive or negative detail and to note this in a "free input box". Lastly participants were asked to indicate whether they had seen the robot before.

2.2.3 Explanatory variables

As explanatory variables the sub-dimensions *extroversion*, *openness* and *neuroticism* with two items each based on a 10-item version of the *Big Five Inventory* (Rammstedt & John, 2007) were measured. With regard to extroversion, people scoring high on this dimension are described as more companionable, talkative, confident, active, and optimistic (Cronbach's α = .82). Neuroticism is the extent to which people describe themselves to be emotionally unstable. People high in neuroticism are more sorrowful, unsure, nervous, anxious and sad, but they are also more empathetic (Cronbach's α = .56). Openness is the extent to which people are curious, inquisitive, and keen on having new experiences and acting more unconventionally (Cronbach's α = .20). The subscales *neuroticism* and *openness* were excluded from further analysis due to low internal reliability.

Further, participants' anxiety towards robots was assessed using the subscale "*Anxiety toward Behavioral Characteristics of Robots*" of the *Robot Anxiety Scale* (Nomura et al., 2007) with four items ("How robots will act", "What robots will do", "What power robots will have", "What speed robots will move at", Cronbach's α = .83)

In addition, participants completed the *FKK Questionnaire for Competence and Control Orientations* (Krampen, 1991) with the sub-dimensions *Self-Concept of Own Competences* which measures the generalized expectation of having action possibilities (at least one) at disposal in life of action situations. ("I do not like ambiguous situations, because I don't know how to react."; Cronbach's α = .73), *Internality* which measures the subjectively noticed control of one's own life and events in the person specific environment ("I can pretty much determine what happens in my life."; Cronbach's α = .63), *Powerful Others Control* which measures the generalized expectation that important events in life depend on the influence of (powerful) others ("I feel that what happens in my life is mostly determined by powerful others."; Cronbach's α = .73). The subscale *Internality* was excluded from further analysis due to low internal reliability.

2.2.4 Sample

The sample comprised 144 complete questionnaires and seven data sets of participants who rated at least 20 of the 40 robots (n = 151, 109 female, 42 male). Participants' age ranged between 18 and 70 years (M = 25.24; SD = 8.22). Participants had a moderate interest in technical topics (M = 4.78, SD = 1.58) and an average interest in robots (M = 3.49; SD = 1.37). Four people stated that they own a robot (iRobot vacuum cleaner, Furby, Robosapien), four indicated that they work with robots, and six indicated that they are involved in research with robots.

2.2.5 Procedure

Participants were recruited via campus advertising and via mailing lists. University students received extra credit for participation. The other participants had the possibility of taking part in a raffle with the chance of winning one of five €20 Amazon gift cards. The survey started with demographic questions (age, gender, education) and questions regarding participants' prior experiences with robots (own a robot, work with robots), and their general interest in technology and their particular interest in robots. Subsequently, they filled in the *BIG Five* questionnaire. Afterwards, they evaluated the 40 robots. The survey concluded with the *Robot Anxiety* and the *FKK* questionnaire. At the end of the questionnaire participants were debriefed, thanked for their participation, and automatically forwarded to a separate webpage where they had the possibility of leaving their email address in order to take part in the raffle.

2.3 Results

Statistical analyses were performed using IBM SPSS for Windows (Release 20.0; August 16th, 2011; SPSS Inc. IBM, Chicago). Kolmogorov-Smirnov tests were calculated to test for normal distribution. For normal distributed data parametric tests like *ANOVAs* and *t* tests were used for further analysis. Data deviating significantly from normal distribution were subject to non-parametric tests. An alpha level of .05 was used for all statistical tests. For curve fitting and model selection RStudio (Release v0.97; May 11th, 2013; RStudio Inc., Boston) was used with the qpcR package for model fitting and model selection (Release 1.7; April 18th, 2013; Andrej-Nikolai Spiess).

2.3.1 Preparatory analyses

As already mentioned most of the robots used in this study are research objects and thus not known among the public. However, for some robots a number of participants indicated that they had already seen the robot before. These robots were Geminoid HI-1 (n=17), Asimo (n=38); HRP-4c (n=13), Phope (n=15); Robosapien (n=19), Leonardo (n=24), Kismet (n=30). To avoid biases in our data we controlled for possible effects of acquaintance with the robots and calculated *ANOVAS* and *Mann-Whitney U* tests with *"know robot before"* as independent variable and *likable, threatening, submissive, unfamiliar, human-like* and *mechanical* as dependent variables. We found effects for three robots. People who knew Geminoid HI-1 before participation in the study rated the robot as more unfamiliar (M = -.15, SD = 1.00; n = 17) compared to those who did not know it before (M = -.77, SD = 1.02; n = 134; F(151,1) = 5.449, p = .021, η^2 = .035). Contrastingly, Kismet was rated as less unfamiliar by people who knew it before (M = .02; SD = .73, N = 30) compared to those who did not see it before (M = .44; SD = .93, n = 114; F(151,1) = 5.267, p = .023, η^2 = .036). Leonardo was rated as more threatening by people who had had no knowledge of the robot before (M = .45; SD = 1.09, n = 24; Knew robot: M = -.00, SD = .83, n = 120; F(151,1) = 5.336, p = .022, η^2 = .036).

2.3.2 General evaluation of robots

The most *Threatening* robots were Geminoid HI, Robonova, REEM-1390, and HRP3, while Autom, Cosmobot, and Papero and Robovie MR2 were rated as least threatening (cf. Table 21). With regard to the robots' *likability,* HRP-4c, Geminoid DK, Autom, and Asimo were rated as the most likable and Robonova, Robosapien, PR2 and Justin as the least likable robots (cf. Table 22).

Table 21: Most and least threatening robots

Most threatening			Least threatening		
	M (SD)	N		M (SD)	N
Geminoid HI-1	1.08 (.07)	151	Cosmobot	-.85 (.04)	151
Robonova	1.05 (.06)	147	Autom	-.90 (.05)	151
REEM-1390	1.04 (.05)	151	Papero	-.78 (.05)	151
HRP3	.82 (.08)	147	RobovieMR2	-.61 (.06)	144

Table 22: Most and least likable robots

Most likable			Least likable		
	M (SD)	N		M (SD)	N
HRP-4c	1.1 (.07)	149	Robonova	-.56 (.05)	147
Geminoid DK	.82 (.07)	149	Robosapien	-.41 (.05)	144
Autom	.72 (.06)	151	PR2	-.45 (.05)	151
Asimo	.53 (.07)	149	Justin	-.27 (.05)	151

Icat, Cosmobot, Asoy, Riban were the robots evaluated as the most *submissive*. Wabian, HRP3, Justin and REEM1390 were rated as least submissive (cf. Table 23). The most *unfamiliar* robots were Lucas, Mika, EMYS and PR2. The least unfamiliar and thus familiar robots are the four android robots in the sample: Geminoid DK, Geminoid HI-1, Ibn Sina and HRP-4c (cf. Table 24). These were also rated as most human-like (cf. Table 25). The most mechanical robots were PR2, Wabian, Armar, and Robonova.

Table 23: Most and least submissive robots

Most submissive			Least submissive		
	M (SD)	N		M (SD)	N
ICat	1.1 (.07)	151	Wabian	-.69 (.06)	149
Cosmobot	.94 (.06)	151	HRP3	-.67 (.06)	144
Asoy	.87 (.07)	151	Justin	-.67 (.06)	151
Riba	.75 (.07)	146	REEM1390	-.59 (.06)	151

Table 24: Most and least unfamiliar robots

Most unfamiliar			Least unfamiliar		
Robot	M (SD)	N	Robot	M (SD)	N
Lucas	.78 (.07)	145	Geminoid DK	-1.10 (.06)	149
Mika	.62 (.06)	145	Geminoid HI1	-.69 (.08)	151
EMYS	.52 (.06)	151	IbnSina	-.58 (.06)	149
PR2	.49 (.07)	150	HRP-4c	-.57 (.06)	149

Table 25: Most human-like and most mechanical robots

Most human-like			Most mechanical		
Robot	M (SD)	N	Robot	M (SD)	N
Geminoid DK	4.89 (.04)	151	PR2	4.58 (.06)	151
Geminoid HI1	4.79 (.04)	149	Wabian	4.40 (.07)	149
HRP-4c	4.40 (.05)	149	Robonova	4.36 (.06)	151
Ibn Sina	4.32 (.07)	149	Armar	4.35 (.07)	151

2.3.3 Cluster analysis

In order to identify clusters of robots and their underlying design characteristics (***RQ1 & RQ2***) mean values were calculated for each robot for the four factors derived from the principal component analysis, namely *likable, threatening, submissive* and *unfamiliar*, and the two items *human-like* and *mechanical*. The resulting values were the basis for the subsequent cluster analysis.

Accordingly, a cluster analysis was run on 40 cases (the 40 robots) with the six aforementioned variables. An agglomerative hierarchical cluster analysis with squared Euclidian distance measures using Ward's minimum variance method (Ward, 1963) was conducted. Data were standardized by converting them to z-scores. The inspection of the re-formed agglomeration table (cf. Table 26) provides no conclusive suggestion of the number of clusters which should be retained for further analysis, because changes in agglomerated coefficients are rather high throughout (Burns & Burns, 2008). The five cluster solution is most reasonable, because it marks the last considerable change in agglomerated coefficients. The dendrogram (cf. Figure 23) also suggested retaining five clusters. However, in the five-cluster solution the fifth cluster contained the four android robots (Geminoid HI-1, Geminoid DK, HRP-4c and ibn Sina) which seemed to differ greatly with regard to the factors *likable* and *threatening*. Because of the limited number of android robots in this stimulus set and given their importance in the overall research topic of examining the uncanny valley, it was decided to work with the six cluster solution which accounts for the differences in the perception of the four androids by dividing them into two clusters.

Table 26: Re-formed Agglomeration Table

No. of clusters	Agglomeration last step	Coefficients this step	Change
2	234	162	72
3	162	103	59
4	103	82	21
5	82	69	13
6	**69**	**61**	**8**
7	61	53	8
8	53	45	8
9	45	38	7
10	38	34	4

Note: Final solution for number of cluster is highlighted in boldface

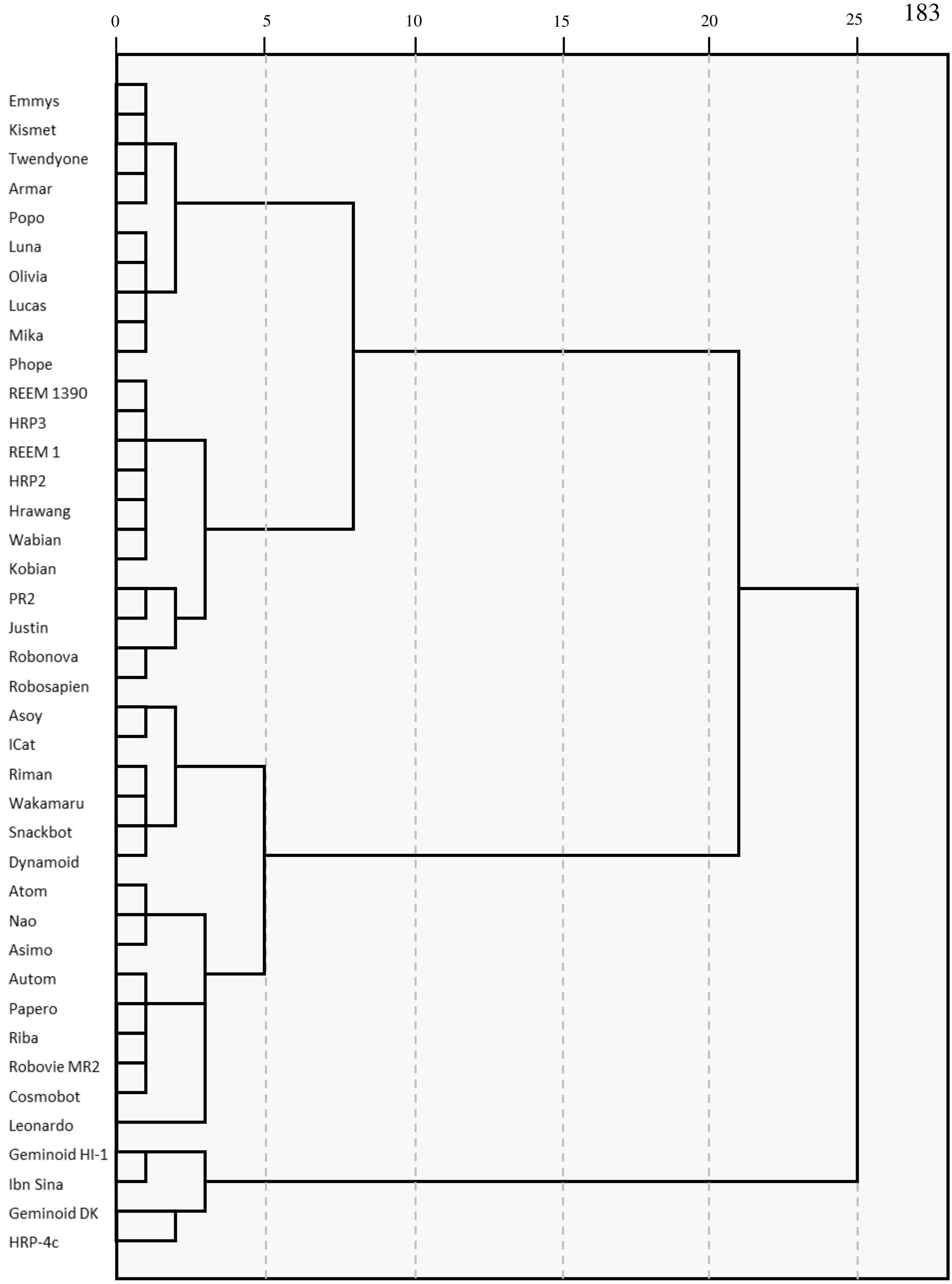


Figure 23: Dendrogram based on the results of the agglomerative hierarchical cluster analysis

The resulting clusters are described in more detail in the following:

Cluster 1 (small, playful robots). The first cluster was characterized by robots which were rated as likable, non-threatening, submissive, not particularly human-like and somewhat mechanical (cf. Figure 24). Robots in this cluster are *Asimo, Atom, Autom, Cosmobot, Leonardo, Nao, Papero, Riba,* and *RobovieMR2*. Apart from Asimo (120 cm), Riba (140cm) and Atom (156cm) these robots are all very small and less than 50 cm in height. Most of the robots have a toy-like appearance (e.g. Cosmobot & Papero which were designed to be companions for children). Half of the robots follow principles of the scheme of childlike characteristics or baby-scheme (Lorenz, 1943) and have rather big heads and big eyes compared to the overall body. The majority are light-colored with white and light blue. The three humanoid robots in this cluster are very softly shaped and more slender (compared to the humanoid robots in cluster 5 (see below) which are very square-edged, bold and clumsy). Two of the most likable robots are in this cluster: Autom and Asimo. The least threatening robots are all part of this cluster (Cosmobot, Autom, Papero, RobovieMR2, cf. Table 21) and two of them were also rated as most submissive (Cosmobot, Riba, cf. Table 23).

Figure 24: Cluster 1: Robovie MR2. Cosmobot. Autom. Papero. Riba. Nao. Asimo. Atom & Leonardo

Cluster 2 (colorful, unusually shaped robots). The robots in the second cluster were again rated as not threatening, submissive, not human-like and somewhat mechanical, but they were slightly more unfamiliar and significantly less likable (cf. Figure 25). The robots in this cluster are *Asoy, Icat, Snackbot, Dynamoid, Riman, Wakamaru.* ICat and Asoy also have a toy-like appearance, because they were designed for interactions with children. The other robots share unusually shaped heads: Ri-Man's head is squared, Wakamaru has a strongly curved "mouth", and the head of Snackbot is very round. Except for Snackbot all the robots are very colorful (ICat, Wakamaru amd Riman, Asoy, Dynamoid). Two of these were rated as most submissive (ICat, Asoy, cf. Table 23).

Figure 25: Cluster 2: Asoy, ICat, Snackbot, Dynamoid, Ri-Man & Wakamaru

Cluster 3 (rather threatening androids) & 4 (rather likable androids). Cluster three and four are very similar. They both contain android robots and were essentially rated as familiar, human-like and non-mechanical and both rather likable and threatening. However, cluster three (with *Geminoid HI-1* and *ibnSina*) was slightly more threatening than cluster four (with *Geminoid DK* and *HRP-4c*). Interestingly, Geminoid HI-1 was rated as the most threatening robot in the sample. And more importantly, cluster four was significantly more likable than cluster three (cf. Figure 26). Both androids in cluster four (HRP-4c and Geminoid DK) were rated as the most likable robots in the sample. All four android robots were rated as the most human-like robots in the sample (cf. Table 25).

Figure 26: Cluster 3 (Geminoid HI-1 & Ibn Sina) & Cluster 4 (Geminoid DK & HRP-4c)

Cluster 5 (threatening mechanical robots). Cluster five was rated as not likable, threatening, dominant, rather unfamiliar, rather not human-like and very mechanical (cf. Figure 27). The robots in this cluster were *PR2, Justin, Robonova, Robosapien, Wabian, REEM1390, REEM1, Kobian, Hwarang, HRP2,* and *HRP3.* Most of these robots are bi-pedal robots. Moreover, these robots are all rather tall except for Robonova and Robosapien. However, these two, as well as the rest of the robots are rather bold and bulky in contrast to the three bi-pedal robots in cluster one. Further, the joints and wiring of some robots are visible. Except for REEM1 and Wabian none of the robots has facial features. Most of them have a round head and wear a visor. Three of the most threatening robots are in this cluster: Justin, HRP3, and Robonova (cf. Table 21). Moreover, three of the most mechanical robots are in this cluster all PR2, Wabian, and Robonova (cf. Table 25).

Figure 27: Cluster 5: PR2. Justin, Robonova, Robosapien, REEM-1390, Wabian, Kobian, HRP2, HRP3, REEM-1, Hwarang

Cluster 6 (unfamiliar, futuristic robots). Cluster six is characterized by non-human-like but mechanical robots rated as neither particularly likable nor threatening, as submissive and very unfamiliar (cf. Figure 28). This cluster was significantly more unfamiliar than any other cluster. The robots in this cluster are *Armar, Popo, Phobe, EMYS, Twendyone, Olivia, Kismet, Luna, Lucas, and Mika.* All of these robots have rather futuristic shapes. Two robots (Kismet and EMYS) are just heads and lack a body. The other robots share the characteristic that they move on wheels. Moreover, robots in this cluster had no or rather limited facial features (e.g. only eyes, but no eye-brows, mouth, nose, etc.).

Figure 28: Cluster 6: Mika, Luna, Olivia, Lucas, Kismet, Armar, Popo, Phobe, EMYS, Twendyone

For internal validation of the clusters ANOVAs were conducted. Variables were significantly different in the main for the six-cluster solution (for mean values and results of ANOVAs cf. Table 27).

Table 27: Between groups differences for likable, threatening, submissive, unfamiliar, human-like and mechanical measures

	Group1 (n=9)		Group2 (n=6)		Group3 (n=2)		Group4 (n=2)		Group5 (n=11)		Group6 (n=10)			
Measure	M	SD	M	SD	M	SD	M	SD	M	SD	M	SD	$F(5,40)$	η^2
Likable	.44	.15	-.16	.12	.06	.08	**.96**	**.19**	-.17	.25	-.07	.06	22.319	.77
Threatening	-.51	.32	-.34	.14	**.80**	**.40**	.31	.40	.57	.31	-.04	.19	21.787	.76
Submissive	.40	.34	**.67**	**.28**	.09	.34	-.35	.05	-.45	.25	-.06	.28	16.539	.71
Unfamiliar	-.11	.24	.13	.12	-.64	.08	-.82	.36	.07	.22	**.45**	**.15**	21.592	.76
Human-like	2.23	0.65	2.08	0.52	4.56	0.33	**4.65**	**0.35**	2.76	0.57	1.94	0.33	17.162	.72
Mechanical	3.13	0.55	3.45	0.25	2.05	0.21	2.21	0.78	**4.08**	**0.32**	3.78	0.31	17.206	.72

Note: highest mean values on each factor highlighted in boldface, for all six effects $p < .001$

Post hoc comparisons for *likable* using the Tukey HSD test indicated that cluster four (more likable androids) was significantly more likable than all the other clusters except for cluster one (small playful robots). Cluster one is significantly more likable than cluster two, five and six. The other groups do not differ significantly in their likability (for mean values and results of post hoc analysis cf. Table 60 in Appendix B).

Post hoc comparisons for *threatening* using the Tukey HSD test indicated that cluster three (more threatening androids), four (more likable androids) and five (threatening mechanical robots) do not differ significantly from one another. However, cluster three and five are significantly more threatening than cluster one, two and six. Moreover, cluster four and six (unfamiliar futuristic robots) were more threatening than cluster one (for mean values and results of post hoc analysis cf. Table 61 in Appendix B)

Post hoc comparisons for *submissive* using the Tukey HSD test indicated that cluster one (small playful robots) and two (colorful, unusually shaped robots) were both significantly more submissive than clusters four, five, and six. Moreover, cluster six was more submissive than cluster five (for mean values and results of post hoc analysis cf. Table 62 in Appendix B)

Post hoc comparisons for *unfamiliar* using the Tukey HSD test indicated that cluster six (unfamiliar, futuristic robots) was significantly more unfamiliar than all the other groups. Cluster two (colorful unusually shaped robots) was more unfamiliar than clusters three and four (androids). Moreover, cluster five (threatening mechanical robots) was more unfamiliar than clusters three and four (for mean values and results of post hoc analysis cf. Table 63 in Appendix B)

Post hoc comparisons for *human-likeness* using the Tukey HSD test indicated that clusters three and four (both android clusters) were both significantly more human-like than all the other clusters, but do not differ from each other. Cluster five (threatening mechanical robots – all bi-pedal) was significantly more human-like than cluster six (for mean values and results of post hoc analysis cf. Table 64 in Appendix B).

Post hoc comparisons for *mechanicalness* using the Tukey HSD test indicated that cluster five (threatening mechanical robots) was significantly more mechanical than clusters one, two, three, and four. Cluster six was significantly more mechanical than clusters one, three, and four. Also cluster two was more mechanical than cluster three and four. And finally, cluster one was more mechanical than cluster three (for mean values and results of post hoc analysis cf. Table 65 in Appendix B).

2.3.4 Relation of human-likeness & mechanicalness ratings

To test the hypothesis that ratings on *human-likeness* and *mechanicalness* correlate negatively (***H1***) mean values for items human-like and mechanical for each robot were calculated and the mean values for the overall 40 robots. Correlation analyses were conducted between the items human-like and mechanical for each of the 40 robots as well as the robots in total.

Regarding the 40 robots in total, results showed that the two variables were negatively correlated ($r(38) = -.40$, $p = .010$). With regard to the single robots results showed similar negative correlations for 35 of the robots. Only five robots did not show correlations between human-likeness and mechanicalness; these were Cosmobot, Lucas, Robovie mR2, Leonardo, and Kismet.

2.3.5 Relation of human-likeness, mechanicalness ratings and the evaluation in terms of person perception

According to ***H2*** and ***H3*** it was examined whether participants' ratings in *human-likeness* or *mechanicalness* predict the evaluation of the robots in terms of person perception (four factors *likable*, *threatening*, *submissive*, *unfamiliar*).

Likability. Human-likeness and mechanicalness both predicted participants' *likable* ratings. Human-likeness significantly predicted likable scores, $\beta= .36$, $t(38) = 2.36$, $p = .024$. Human-likeness also explained a significant proportion of variance in likable scores, $R^2 = .13$, $F(1, 39) = 5.57$, $p = .024$. Moreover, mechanicalness significantly predicted likable scores, $\beta = -.57$, $t(38) = 4.27$, $p < .000$. Mechanicalness also explained a significant proportion of variance in likable scores, $R^2 = .32$, $F(1, 39) = 18.25$, $p < .001$.

Threatening. Mechanicalness was not a predictor for *threatening*, but human-likeness. Human-likeness significantly predicted threatening scores, $\beta = .528$, $t(38) = 3.84$, $p = .000$. Human-likeness also explained a significant proportion of variance in threatening scores, $R^2 = .28$, $F(1, 39) = 14.71$, $p = .000$.

Submissive. Human-likeness significantly predicted submissive scores, $\beta = -.756$, $t(38) =-3.16$, $p = .003$. Human-likeness also explained a significant proportion of variance in submissive scores, $R^2 = .21$, $F(1, 39) = 9.97$, $p = .003$. Mechanicalness significantly predicted submissive scores, $\beta = -.361$, $t(38) = -2.39$, $p = .022$. Mechanicalness also explained a significant proportion of variance in submissive scores, $R^2 = .13$, $F(1, 39) = 5.71$, $p = .022$.

Unfamiliar. Mechanicalness and human-likeness are both predictors for unfamiliar Scores. Mechanicalness was a predictor for unfamiliar scores. Mechanicalness significantly predicted unfamiliar scores, $\beta = .680$, $t(38) = 5.72$, $p <.001$. Mechanicalness also explained a significant proportion of variance in unfamiliar scores, $R^2 = .46$, $F(1, 39) = 32.74$, $p < .001$. Human-likeness significantly predicted unfamiliar scores, $\beta = -.735$, $t(38) =-6.69$, $p < .001$. Human-likeness also explained a significant proportion of variance in unfamiliar scores, $R^2 = .54$, $F(1, 39) = 44.70$, $p < .001$.

2.3.6 Reproducing the uncanny valley

In order to answer ***RQ3*** it was examined which mathematical function (linear, quadratic, cubic) fits the obtained data best. As Burleigh et al. (2013) conclude the uncanny valley theory predicts a nonlinear relationship between human-likeness and some uncanny valley related response on the side of the user. A common procedure to probe for the uncanny valley function is to plot ratings for human-likeness and the uncanny valley related response (in most cases these are ratings for uncanniness or eeriness of the particular stimulus; e.g., Hanson et al., 2005; Hanson, 2006; Lay, 2006; MacDorman, 2006; MacDorman & Ishiguro, 2006; MacDorman et al., 2009; Tinwell & Grimshaw, 2009). Most authors of previous studies did so in a more descriptive way. However, in this study (following the approach of Burleigh et al.) quadratic or cubic models were tested to establish which fit the data obtained within this study best. In contrast to previous studies, not only human-like but also mechanical ratings were used to predict participants' responses. Moreover, based on Ho and MacDorman's observations that "shinwakan and bukimi appear to constitute distinct dimensions" (with shinwa-kan translated as likability/affinity and bukimi translated as eeriness; Ho & MacDorman, 2010, p. 1508), both the evaluation of the robots with regard to the factors Likability and Threatening were considered for analysis. Hence, mean values of *human-likeness* and *mechanicalness* ratings as well as mean values for the factors *likable* and *threatening* were plotted (cf. Figure 29) and linear, quadratic, and cubic functions were fit to the data.

Burleigh et al. (2013) chose the Akaike Information Criterion (AIC, Akaike 1973, cited by Burnham & Anderson, 2002), because AIC penalizes the addition of parameters, and thus selects a model that fits well but has a minimum number of parameters. This is important, because of the principle of simplicity and parsimony in information theory which suggests that the simplest explanation is probably the most likely. However, Burn and Anderson (2002) propose to use the second-order Akaike Information Criterion (AIC_c) for small sample sizes (i.e., n /V < 40, with n= sample size, V=number of parameters). Given the number of data points, the corrected formula AIC_c was used in which k is the number of parameters, and L is the maximized value of the likelihood function:

$$AIC_c = -2 \log L + 2\text{V} + \frac{2V(V+1)}{n-V-1}$$

In general, lower AIC values mean more goodness-of-fit. However, there are additional indices to better compare the tested models. First, the delta AIC (Δ_i) can be compared which calculates the differences in AIC with respect to the AIC of the best candidate model. Delta AIC is calculated as follows,

$$delta\ AIC = \Delta_i = AIC_i - \min AIC,$$

with AIC_i as the AIC value for model i, and min AIC as the AIC value of the "best" model (Akaike, 1973; Burnham & Anderson, 2002; Wagenmakers & Farrell, 2004). Burnham and Anderson (2002) suggest that deltas smaller than two ($\Delta_i < 2$) indicate substantial evidence for the model. Deltas between 3 and 7 indicate less support for the model and deltas larger than 10 indicate that the model is very unlikely. On the basis of delta AICs another measure is calculated; the Akaike Weights. First, deltas are transformed to obtain an estimate of the relative likelihood (*L*) of a model,

$$L(M_i|data) \propto exp\left\{-\frac{1}{2}\Delta_i\,(AIC)\right\},$$

and finally the relative model likelihoods are normalized to obtain Akaike weights (w_i(AIC)):

$$w_i(AIC) = \frac{\exp\left\{-\frac{1}{2}\Delta_i\,(AIC)\right\}}{\sum_{k=1}^{k}\exp\left\{-\frac{1}{2}\Delta_k(AIC)\right\}}$$

Akaike Weights "can be interpreted as the probability that M_i is the best model (in the AIC sense, that it minimizes the Kullback-Leibner discrepancy) given the data and the set of candidate models (e.g. Burnham and Anderson, 2001)" (Wagenmakers & Farrell, 2004, p. 194). The strength of evidence for one particular model over the other models is achieved by dividing the Akaike weights of the models. If the result, also called evidence ratio, is smaller than 2.7 (w_{m1}(AIC)/ w_{m2}(AIC) <2.7) the models can be regarded as statistically equivalent in which case the principle of parsimony suggests sticking to the simpler model. Moreover, Royall 1997 recommended generating a confidence set of models by including models with Akaike weights within 10% of the highest value. This confidence set can be seen as a confidence interval.

The scatterplots of the *human-likeness* and *mechanicalness* ratings with the ratings for the factors *likable* and *threatening* are displayed in Figure 29-32. Altogether they suggest that the four android robots received substantially different ratings in human-likeness (higher ratings for androids) and mechanicalness (lower ratings for androids and for the robot Leonardo) compared to the other 36 robots (see colored data points).

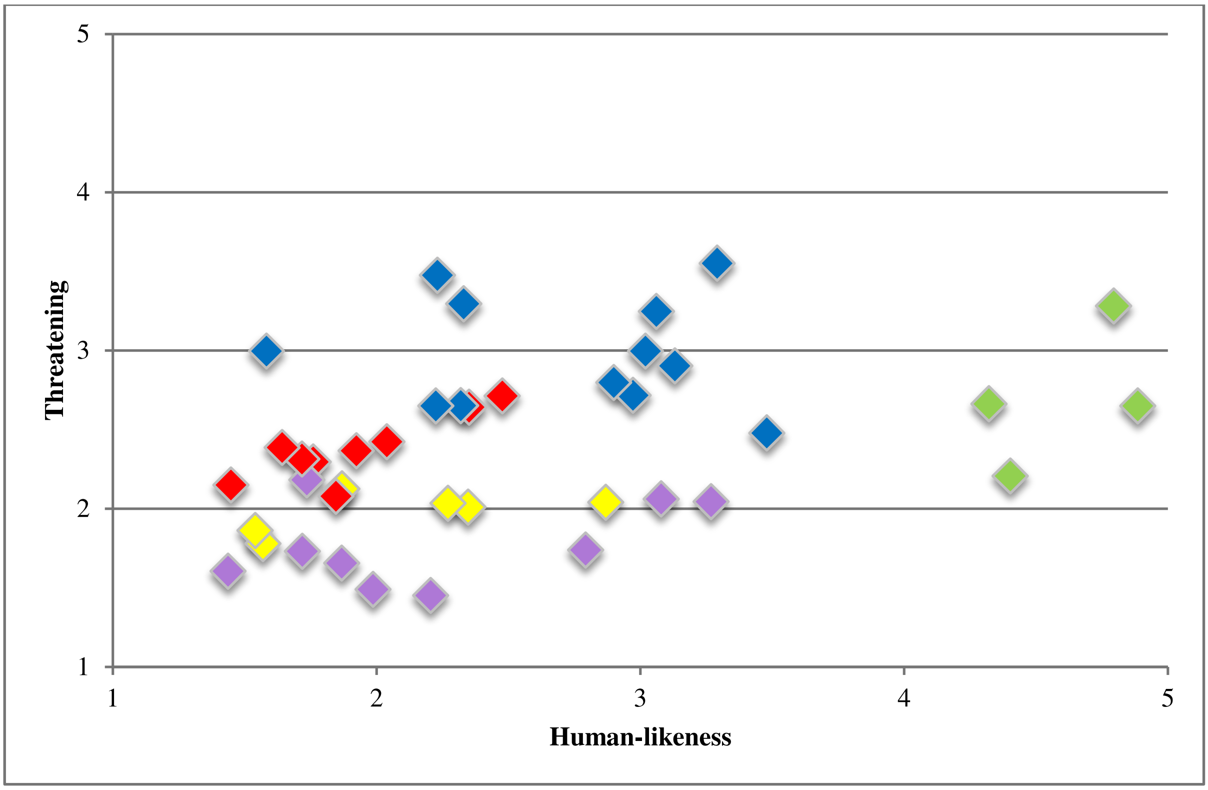


Figure 29: Scatterplot for the human-likeness ratings with the ratings on the factor threatening– Data points are colored according to clusters: purple Cluster 1, yellow Cluster 2, green Cluster 3 and 4, blue Cluster 5, red Cluster 6

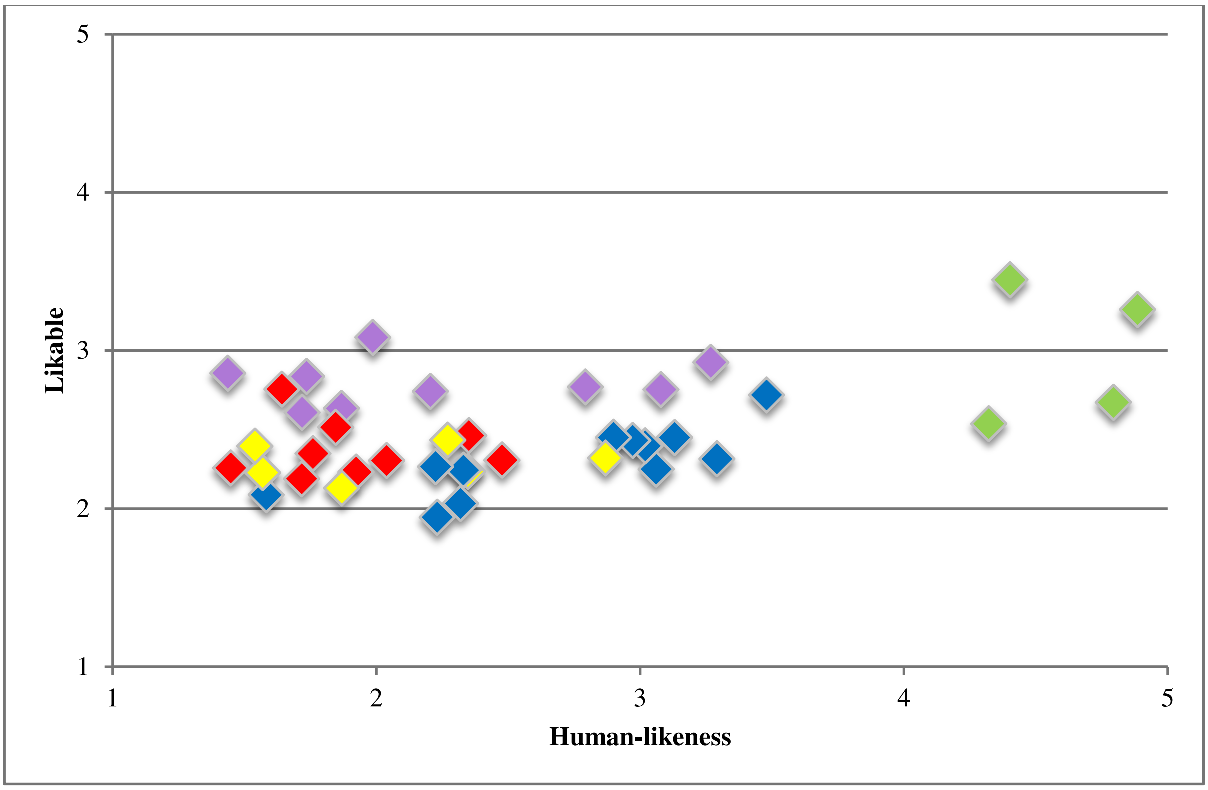


Figure 30: Scatterplot for the human-likeness ratings with the ratings on the factor likable – Data points are colored according to clusters: purple Cluster 1, yellow Cluster 2, green Cluster 3 and 4, blue Cluster 5, red Cluster 6

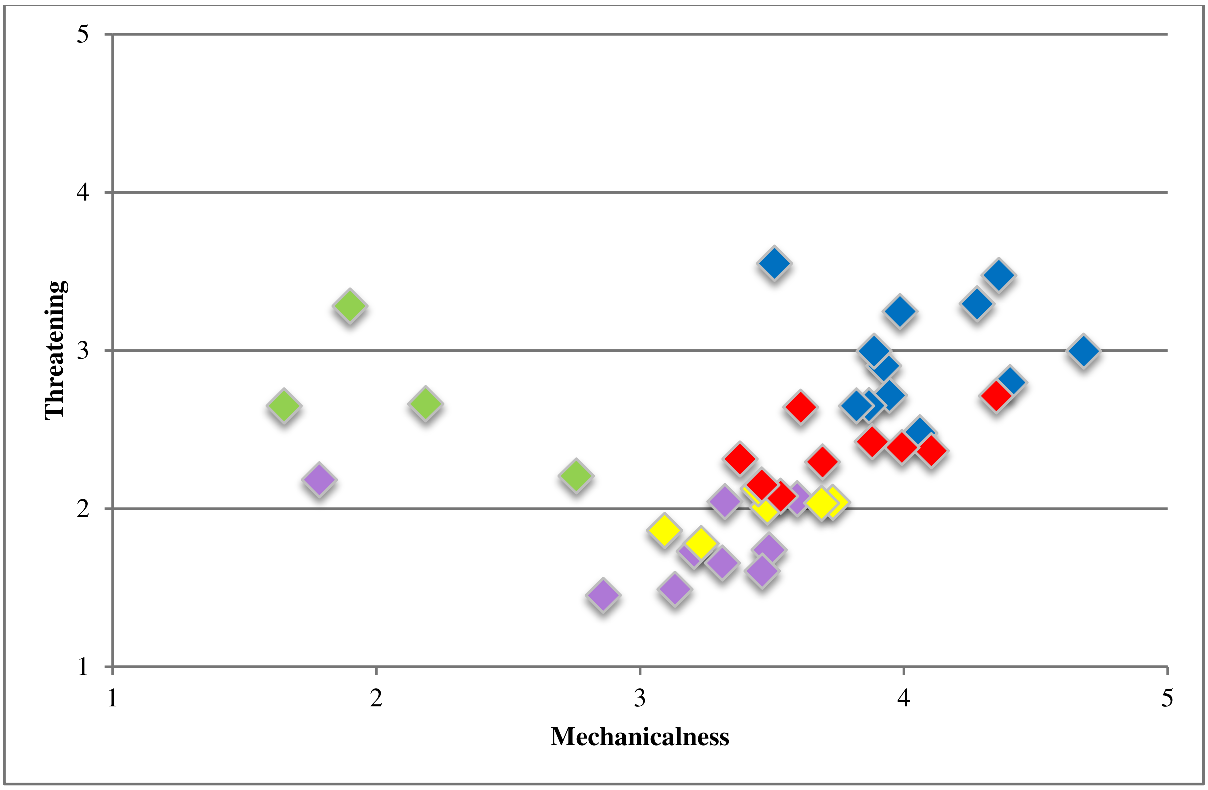


Figure 31: Scatterplot for the mechanicalness ratings with the ratings on the factor threatening – Data points are colored according to clusters: purple Cluster 1, yellow Cluster 2, green Cluster 3 and 4, blue Cluster 5, red Cluster 6

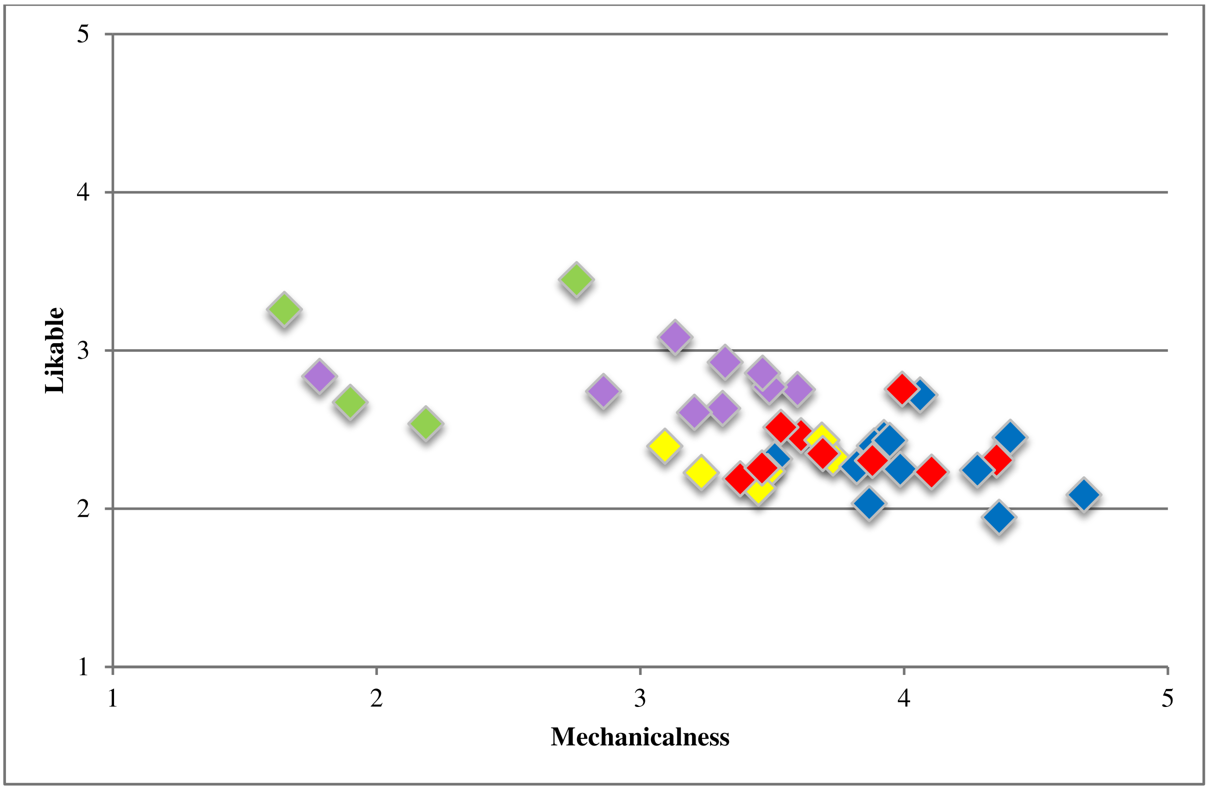


Figure 32: Scatterplot for the mechanicalness ratings with the ratings on the factor likable – Data points are colored according to clusters: purple Cluster 1, yellow Cluster 2, green Cluster 3 and 4, blue Cluster 5, red Cluster 6

Moreover, the data exhibited a strong tendency towards the center for the *likable* ratings, while the ratings for *threatening* showed more variance. Linear, quadratic and cubic functions were fit to the data. The results of these curve estimations and the results of the model comparisons are presented in Tables 28 and 29.

Human-likeness. For the relationship of subjective ratings on *human-likeness* of the robots and their ratings on the factor *threatening* the linear and the quadratic function both showed deltas smaller than 2 (Δ_i <2) suggesting substantial evidence for both models. Moreover, the evidence ratio was smaller than 2.7 (w_{linear}(AIC)/ $w_{quadratic}$(AIC) =1.54). Hence, the models can be regarded as statistically equivalent in which case the principle of parsimony suggests sticking to the simpler model which is the linear model. However, all three models were within the confidence set, because their Akaike weights were higher than the 10% cut off value of the highest Akaike weight (.05, cf. Table 28). Figure 33 shows the estimated model curves for the linear and the quadratic model.

For the relationship of subjective ratings for *human-likeness* of the robots and their ratings for the factor *likable* the quadratic and the cubic function both showed deltas smaller than 2 (Δ_i <2) suggesting substantial evidence for both models. Moreover, the evidence ratio was smaller than 2.7 ($w_{quadratic}$(AIC)/ w_{cubic}(AIC) =2.37). Hence, the models can be regarded as statistically equivalent in which case the principle of parsimony suggests sticking to the simpler model which is the quadratic model. However, all three models were within the confidence set, because their Akaike weights were higher than the 10% cut off value of the highest Akaike weight (.05, cf. Table 28), thus, the linear model was also suited to explaining the data (cf. results in section V.2.3.5). Figure 34 shows the estimated model curves for the linear and the quadratic model.

Table 28: Akaike's second-order information criterion (AICc) of the models human-likeness x threatening and human-likeness x likable

	model	*log-likelihood*	*RSS*	*AIC_c*	*Δ_i (AIC)*	*w_i (AIC)*	*R^2*	*CI*
threatening	**linear**	**1.00**	**32.54**	**111.58**	**0.00**	**0.54**	**.16**	**.05**
	quadratic	0.64	31.39	112.48	0.91	0.35	.19	-
	cubic	0.21	31.21	114.74	3.16	0.11	.19	-
likable	linear	0.35	31.30	110.02	2.13	0.20	.20	.05
	quadratic	**1.00**	**27.99**	**107.90**	**0.00**	**0.57**	**.28**	**-**
	cubic	0.42	27.48	109.65	1.75	0.24	.29	-

Note: best model in boldface

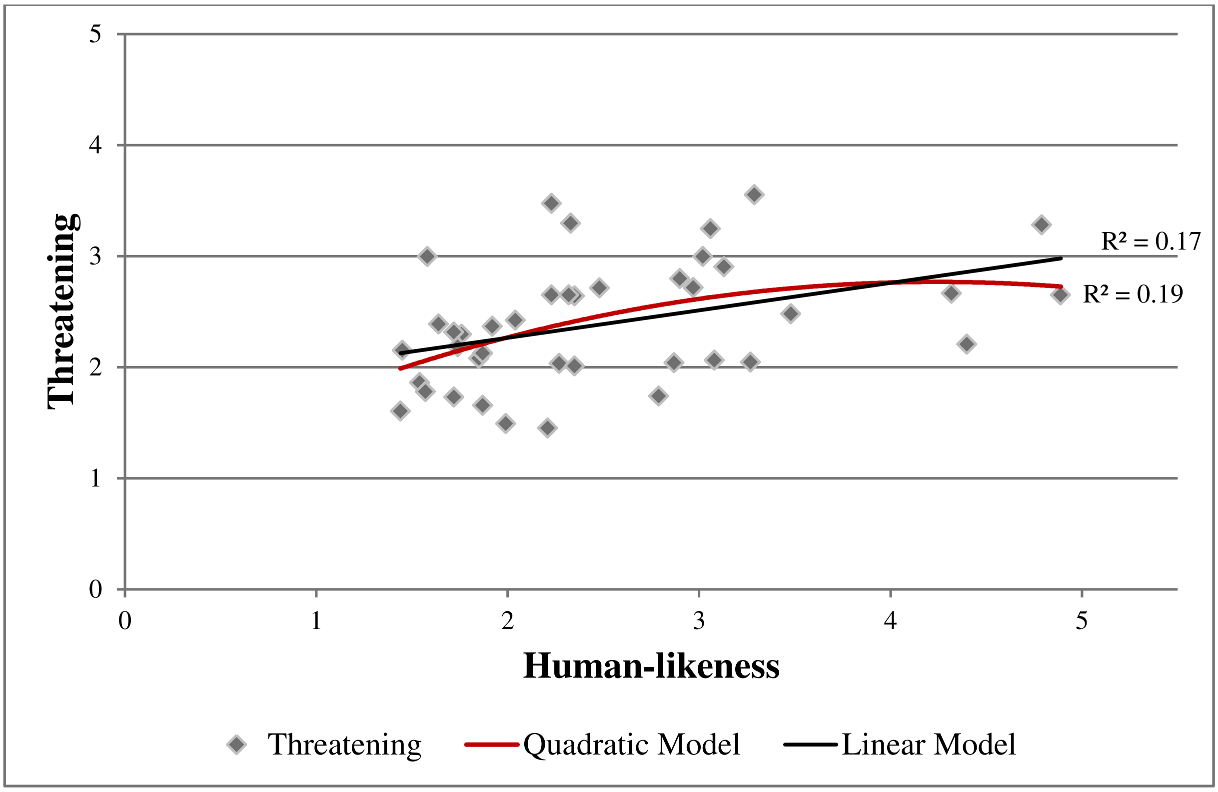


Figure 33: Scatterplots for the human-likeness ratings with the ratings on the factor threatening including the graphical depiction of the best fitting model curve (linear in black) and alternatively the quadratic model (in red)

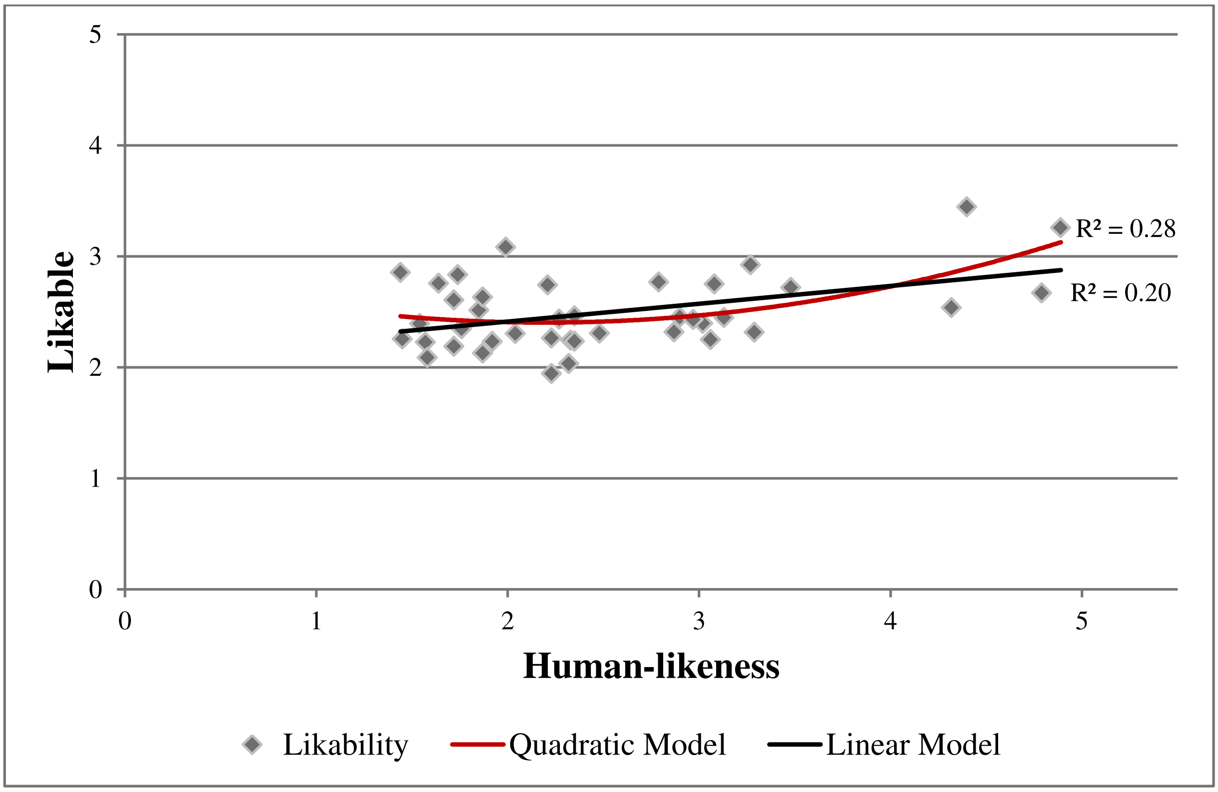


Figure 34: Scatterplots for the human-likeness ratings with the ratings for the factor likable including the graphical depiction of the best fitting model curve (quadratic in red) and alternatively the linear model (in black)

Mechanicalness. For the relationship of subjective ratings for *mechanicalness* of the robots and their ratings for the factor *threatening,* the quadratic and the cubic function both showed deltas smaller than 2 (Δ_i <2) suggesting substantial evidence for both models. Moreover, the evidence ratio was smaller than 2.7 ($w_{linear}(AIC)/ w_{quadratic}(AIC) = 1.56$). Hence, the models can be regarded as statistically equivalent in which case the principle of parsimony suggests sticking to the simpler model which is the quadratic model. In this case only the quadratic and the cubic model were within the confidence set, because the linear model failed to achieve the 10% cut off value of the highest Akaike weight (.06, cf. Table 29, cf. also results in section V.2.3.5 where no valid regression model emerged for *mechanicalness* and *threatening*). Figure 35 shows the estimated model curves for the linear and the quadratic model. According to the quadratic model very mechanical robots (e.g. PR2, Wabian, Robonova, Armar, Justin, Kobian) and androids robots which are rated as least mechanical are perceived as threatening. However, robots with average ratings on mechanicalness (e.g. Cosmobot, Papero, Autom, Robovie MR2) are least threatening.

For the relationship of subjective ratings for *mechanicalness* of the robots and their ratings for the factor *likable* the linear function showed a delta smaller than 2 (Δ_i <2) suggesting substantial evidence for this model. Moreover, the evidence ratios were larger than 3 suggesting that the linear model is not statistically equivalent to the other models. Moreover, only the linear and the quadratic model were within the confidence set, because the Akaike weight of the cubic model is below the 10% cut off value of the highest Akaike weight (.07, cf. Table 29). Figure 36 shows the estimated model curves for the linear and the quadratic model.

Table 29: Akaike's second-order information criterion (AICc) of the models mechanicalness x threatening and mechanicalness x likable

	model	*log-likelihood*	*RSS*	*AIC_c*	*Δ_i (AIC)*	*w_i (AIC)*	*R^2*	*CI*
threatening	linear	0.00	36.05	115.68	17.06	0.00	.08	.06
	quadratic	**1.00**	**22.20**	**98.62**	**0.00**	**0.61**	**.43**	**-**
	cubic	0.63	21.34	99.53	0.91	0.39	.45	-
likable	**linear**	**1.00**	**25.38**	**101.64**	**0.00**	**0.70**	**.35**	**.07**
	quadratic	0.34	25.28	103.82	2.18	0.23	.35	-
	cubic	0.10	25.24	106.23	4.59	0.07	.35	-

Note: best model in boldface

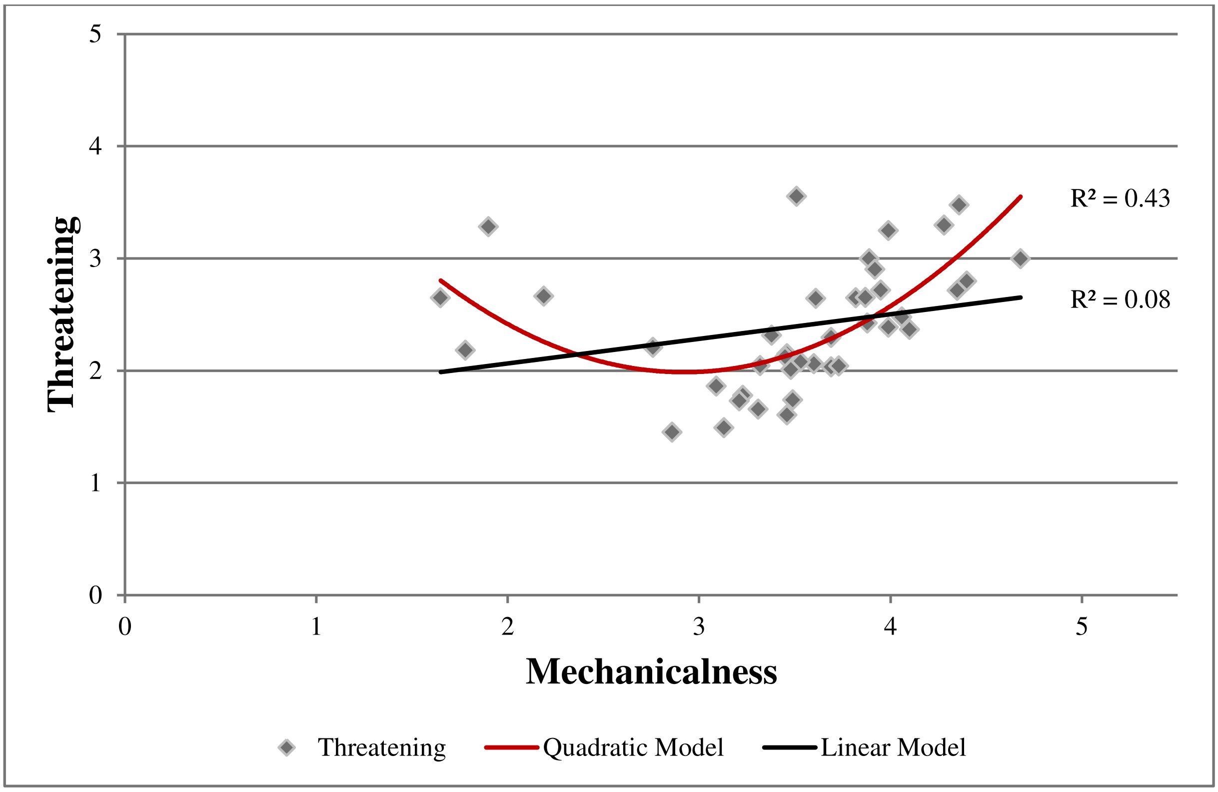


Figure 35: Scatterplots for the mechanicalness ratings with the ratings for the factor threatening including the graphical depiction of the best fitting model curve (quadratic in red) and alternatively the linear model (in black)

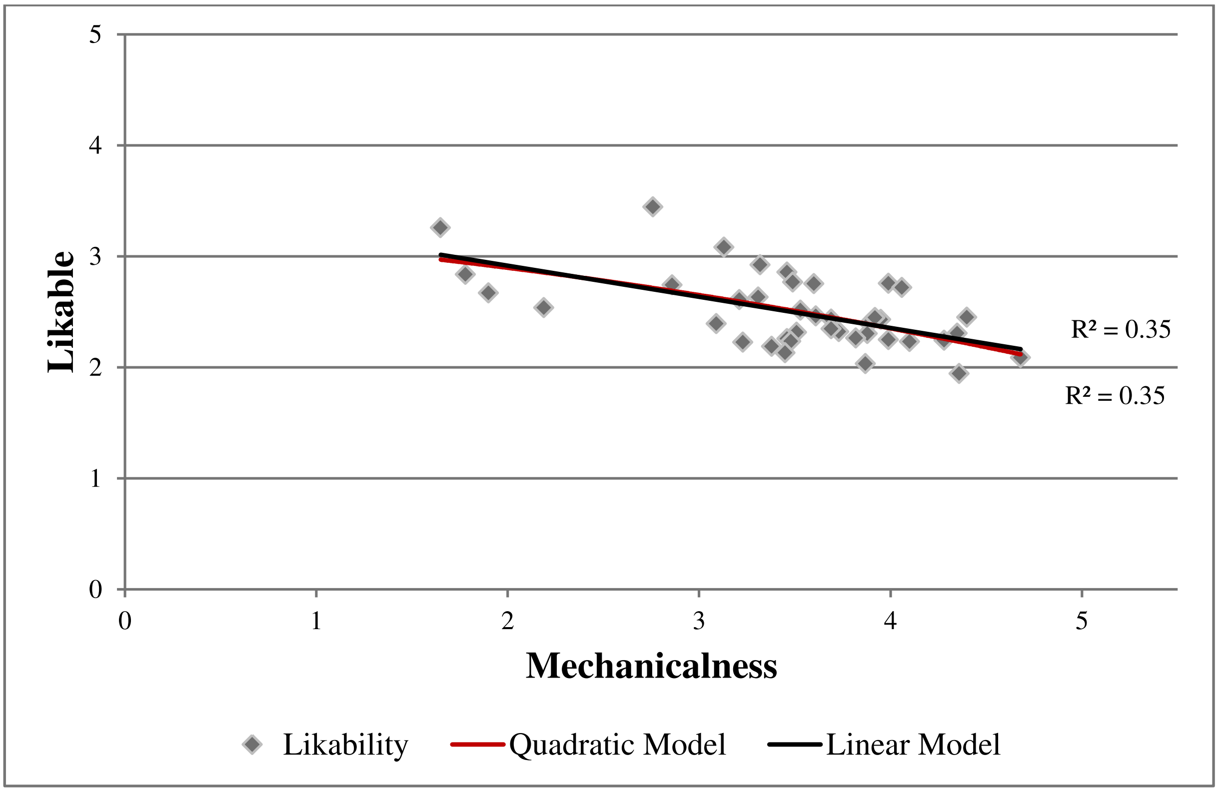


Figure 36: Scatterplots for the mechanicalness ratings with the ratings for the factor likable including the graphical depiction of the best fitting model curve (linear in black) and alternatively the quadratic model (in red)

2.3.6 Influence of participants' personality, gender and technological affinity on evaluation of robots

Furthermore, it was examined whether the participants' gender, their personality and characteristics can predict the overall evaluation of the robots (see ***RQ4 & H4***). For this purpose, mean values for each participant with regard to their overall ratings for the four person perception factors were calculated. Subsequently, regression analyses were conducted with *overall-likable, overall-threatening, overall-submissiveness* and *overall-unfamiliar* as dependent variables and the following predictors: gender, interest in technology, interest in robots, the sum scores of the BIG FIVE subscale extraversion, the sum scores of the FKK subscales powerful others control and self-efficacy and the sum score of the Robot Anxiety Scale.

Results show, that participants' general interest in technology and their particular interest in robots were not predictive. FFK self-efficacy was also not predictive.

However, with regard to Robot Anxiety results show an effect partially conforming to H4. For the person perception factor *overall-threatening* a valid regression model (β= .27, $t(142)$ = 3.35, p = .001) emerged for Robot Anxiety. Robot Anxiety also explained a significant proportion of variance in the *overall-threatening* scores, R^2 = .07, $F(1, 142)$ = 11.21, p = .001.

With regard to overall-Submissive, three variables were predictive. FKK-P (powerful others control) significantly predicted *overall-submissive* (β = .249, $t(149)$ = 3.13, p = .002). FKK-P also explained a significant proportion of variance in the *overall-submissive* scores, R^2 = .06, $F(1, 150)$ = 9.82, p = .002. Moreover, extroversion significantly predicted *overall-submissive* (β = -.180, $t(149)$ = -2.23, p = .027). Extroversion also explained a significant proportion of variance in the *overall-submissive* scores, R^2 = .03, $F(1, 150)$ = 4.97, p = .027. Also gender significantly predicted the *overall-Submissiveness* scores in that men evaluated the robots overall as more submissive, β= .206, $t(149)$ = 2.58, p = .011. Gender also explained a significant proportion of variance in *overall-submissiveness* scores, R^2 = .04, $F(1, 150)$ = 6.63, p = .011.

No valid regression models emerged for *overall-likable* and *overall-unfamiliar*.

2.4 Discussion

The goal of this study was to identify clusters of robots which are evaluated similarly on specific variables and to examine these clusters with regard to characteristics of appearance which were shared among the robots in the specific cluster ***(RQ1 & RQ2)***. Six groups of robots were identified which were significantly differently rated in six dimensions (*likable, threatening, submissive, unfamiliar, human-likeness, mechanicalness*).

2.4.1 Summary of the clusters

The first cluster with small and toy-like robots was rated as likable, not threatening, submissive, not particularly human-like and averagely mechanical. The robots in this cluster were among the least threatening robots in the whole set. Strikingly, half of the robots follow principles of the baby-scheme (big head, large eyes; cf. Glocker et al., 2009; Hückstedt, 1965; Lorenz, 1943). The baby-scheme seems to elicit relevant ratings (submissive, likable, non-threatening, cf. Glocker et al., 2009). While in the interviews in Study 1 participants reported about mixed feelings with regard to the baby-scheme (CB2 and Nexi) in this study the baby-scheme seems to elicit according ratings (submissive, likable, not threatening). Moreover, preferences with regard to the shape of the robots' bodies (round shapes, finished and polished design) as mentioned in the interviews seem to contribute to the positive ratings in this cluster, since the humanoid robots in this cluster were very softly shaped and slender.

The second cluster contained colorful robots with a toy-like appearance, but unusually shaped heads, and was rated as non-threatening, submissive, non-human-like, averagely mechanical, rather unfamiliar and less likable (compared to cluster 1).

Cluster three and four contained the four android robots and were rated as familiar, human-like, non-mechanical, both likable and threatening. The clusters differ in that robots in cluster three (Geminoid HI-1 & ibnSina) were perceived as slightly more threatening. Moreover, cluster four (HRP-4c & Geminoid DK) was significantly more likable than cluster three. Not surprisingly, all four android robots were the most human-like robots. Interestingly, HRP-4c and Geminoid DK were rated as the two most likable robots in the sample, whereas Geminoid HI-1 was perceived as the most threatening robot. As mentioned earlier, it can be assumed that android robots will underlie the same principles for judging attractiveness as humans, because they show a closely human-like appearance (Sobieraj, 2012). If this is the case, then more attractive androids were also rated more positively in other aspects such as likability (c.f. Dion et al., 1972; Eagly, Ashmore, Makhijani, & Longo, 1991). From the differences in likability of the two groups it is obvious that mere human-likeness does not result in high likability, but that other, more specific aspects of appearance were influential. Participants had the chance to report positive and negative details about the robot after they saw them. Seventeen participants criticized Geminoid HI-1 for its stern facial expression (which is actually no facial expression, but the inactive face) whereas HRP-4c was often perceived as likable because of its obvious female gender (seven positive statements referred to gender). Thus, both the assumed facial expression as well as the robots' gender could have influenced participants' evaluation (cf. for gender Bem, 1981; Eyssel & Hegel, 2012; cf. for facial expressions Lau, 1982). Furthermore, three of the robots (HRP-4c, Geminoid HI-1 and ibnSina) were modelled after actual Asian or Arabic people, while Geminoid DK is the only android modelled after a European White person. Thus, there might have been an in-group bias in likability ratings in that the predominantly European White participants evaluated the ethnically in-group android more favorably than the ethnically out-group android robots (cf. Bargh, 1999; Devine, 1989; Eyssel & Kuchenbrandt, 2012; Jussim, Nelson, Manis, & Soffin, 1995). However, these findings can only be assumptions and taken as hints for further investigation rather than conclusions, because neither attractiveness, facial expressions, gender nor ethnicity have been systematically varied in this limited stimulus set of only four android robots.

Cluster five contained mostly tall and bi-pedal robots and was rated as not likable, threatening, dominant, rather unfamiliar, rather non-human-like and very mechanical. Besides being bi-pedal the robots in this cluster shared the fact that most of them were rather bold and bulky and in some robots the joints and wiring were visible. Most robots had no facial features, had a round head, and wore a visor. Interestingly, this cluster was rated only slightly more human-like than cluster one or two, although robots in cluster five throughout had a more human-like figure with definite torso, head, arms, hands, and legs. Moreover, these robots received the highest ratings in mechanicalness and rather low ratings in human-likeness. This is to some extent in contrast to the naïve assumption that exactly these features (having a head, torso, arms and legs) were associated with the human-like appearance of the robots (cf. Ramey, 2006; von der Pütten, 2012). Furthermore, this also contradicts the general assumption in Mori's hypothesis that humanoid robots are also perceived as being more human-like. It seems that the overall more bolder and more bulky appearance undermined a possible positive effect of a human-like figure. In addition, three of the robots in this cluster were among the most threatening ones and three among the most mechanical ones.

Finally, cluster six contained robots in rather futuristic shapes and was rated as not human-like, mechanical, neither likable, nor particularly threatening, submissive and very unfamiliar. This cluster was significantly more unfamiliar than any other cluster. Shared characteristics were the futuristic shapes and that the majority of the robots moved on wheels.

Robots in this cluster had no or rather limited facial features (e.g. only eyes, but no eye-brows, mouth, nose, etc.).

2.4.2 Comparisons of clusters & influence of human-likeness and mechanicalness

When comparing the clusters, results showed that in two clusters (cluster one and cluster two) robots were rated both low in human-likeness and low in mechanicalness. Moreover, correlation analyses revealed that for five robots no correlation could be found between human-likeness and mechanicalness.

Furthermore, mechanicalness and human-likeness predicted *unfamiliar* ratings. Looking at the most familiar robots, it becomes obvious that in this case participants understood familiarity in terms of *familiar according to the human stereotype*. However, looking at the most unfamiliar robots, these robots have relatively unusual forms (futuristic shapes) and would not be seen as reflecting to the robot stereotype as depicted by participants in the interviews (which was predominantly that of a humanoid robot). Thus, it can be assumed that the classic humanoid robot (as in cluster 5) can be found somewhere between the futuristic and unusually shaped robots and the very familiar android robots as is indicated by the mean rating of the cluster. With regard to the uncanny valley hypothesis, this result supports the critique that familiarity (or in this case unfamiliarity) is not adequate for measuring an uncanny valley related response, because of its ambiguousness (cf. Bartneck et al., 2007; Bartneck et al., 2009).

With regard to *threatening* and *submissive*, results showed that the robots in those clusters with a high mean in *threatening* were almost all bi-pedal robots or android (clusters 3-5). Furthermore, the regression analyses showed that human-likeness, not mechanicalness predicted *threatening* by means of a linear regression. However, mechanicalness predicted Threatening by means of a quadratic function (see below). Furthermore, both - human-likeness and mechanicalness - served as predictors for *submissive*.

In contrast to the humanoid robots (cluster 5), the android robots (cluster 3&4) were rated higher on *likable* which contrasts the uncanny valley hypothesis. In cluster 4 one android robot (HRP-4c) is explicitly recognizable as a robot, because of the metal body. Still, HRP-4c is the second most likable robot. Moreover, the regression analyses revealed that human-likeness and mechanical both predicted *likable* ratings. This is especially interesting, because, as mentioned previously, the human-likeness ratings as well as the likability ratings of cluster five were contradictory to the assumption in Mori's hypothesis that humanoid robots are also perceived as being more human-like and thus more likable which was not the case for cluster five.

These results support Ho and MacDorman's (2010) assumption that shinwa-kan (likability or affinity) and bukimi (eeriness or "negative affinity" in this case *threatening*) might be distinct dimensions. Therefore, when testing which model (linear, quadratic, cubic) best fitted to the obtained data (***RQ3***) four combinations of predictors and dependent variables were used (human-likeness x likable; human-likeness x threatening; mechanicalness x likable; mechanicalness x threatening).

Regarding human-likeness, the model comparison suggested that for both dependent variables (*likable* and *threatening*) all three models were in the confidence set of possible fitting models and in addition the respective "best" model had only a 54% or 57% chance of being the best one among those considered in the set of candidate models. Thus, there was no striking evidence for the respective best model. However, with regard to *threatening* the linear model provided the best model fit and with regard to *likable* the quadratic model provided the best model fit. Consulting the results from the regression analyses, it was found that human-likeness can account for up to 28% of variance in the data which is a rather low percentage compared to the over 80% in the studies by Burleigh et al. (2013). However, it has to be acknowledged that the stimulus material in the two studies differed in several dimensions. In this online survey pictures of actual robots were used and these robots differed greatly in their appearance with regard to their overall shape, color, height, the detail of the head and so on. Moreover, variations between robots were neither systematically nor gradually varied. In the Burleigh et al. study virtual faces were used. First, these faces are per se more human-like than the average robot. More precisely, this stimulus material would be concentrated at the far right end of the human-likeness scale, while the actual robots are more widly spread along the human-likeness dimension. In contrast to the actual robots, realism was systematically varied in precisely defined gradual steps. In consequence, the scatterplots of the robots show a rather widespread distribution whereas data points in the scatterplots for the virtual faces are much more concentrated and clearly showed linear relationships.

Regarding mechanicalness, the model comparison suggested that for the dependent variable *threatening* the linear model was not in the confidence set of possible fitting models, which is also reflected in the regression analysis. Here mechanicalness was also not a predictor for *threatening*. However, the quadratic and the cubic model were in the confidence set and the quadratic model received the best model fit (with 61% chance of being the best one among those considered in the set of candidate models). The quadratic model also accounts for 43% of variance. In the model comparison for the dependent variable *likable,* the linear model received the best model fit (with 70% chance of being the best one among those considered in the set of candidate models). The linear model also accounts for 35% of variance. In this case, the quadratic model was statistically not equivalent and the cubic model was not in the confidence set at all.

Similarly to Burleigh et al. (2013) the data in this study could not be explained by a cubic function as would be suggested by the uncanny valley graph proposed by Mori (1970; see also the Figure 37 in which *Mori's hypothetical graph* is presented within the scatterplots for demonstration purposes). In contrast, results overall suggested a linear relationship between human-likeness and *threatening* (bukimi) and a linear or quadratic relationship between human-likeness and *likable* (shinwa-kan). Furthermore, results suggested a linear relationship for mechanicalness and likability*:* the more mechanical a robot is perceived to be, the less likable this robot is perceived to be. Only the relationship between mechanicalness and Threatening was clearly not linear but quadratic. According to the quadratic model very mechanical robots and least mechanical robots (android robots) are perceived as most threatening, while averagely mechanical robots are least threatening.

Moreover, the results of this study support Ho and MacDorman's (2010) assumption that shinwa-kan (likability or affinity) and bukimi (eeriness or "negative affinity") might be distinct dimensions, because both dependent variables were explained best by different (linear versus quadratic) models. If this assumption holds true, then the graph itself would be misleading, because it would integrate participants' responses to two dependent variables in one dependent variable, thereby distorting the real relationship between human-likeness and affinity or eeriness, respectively.

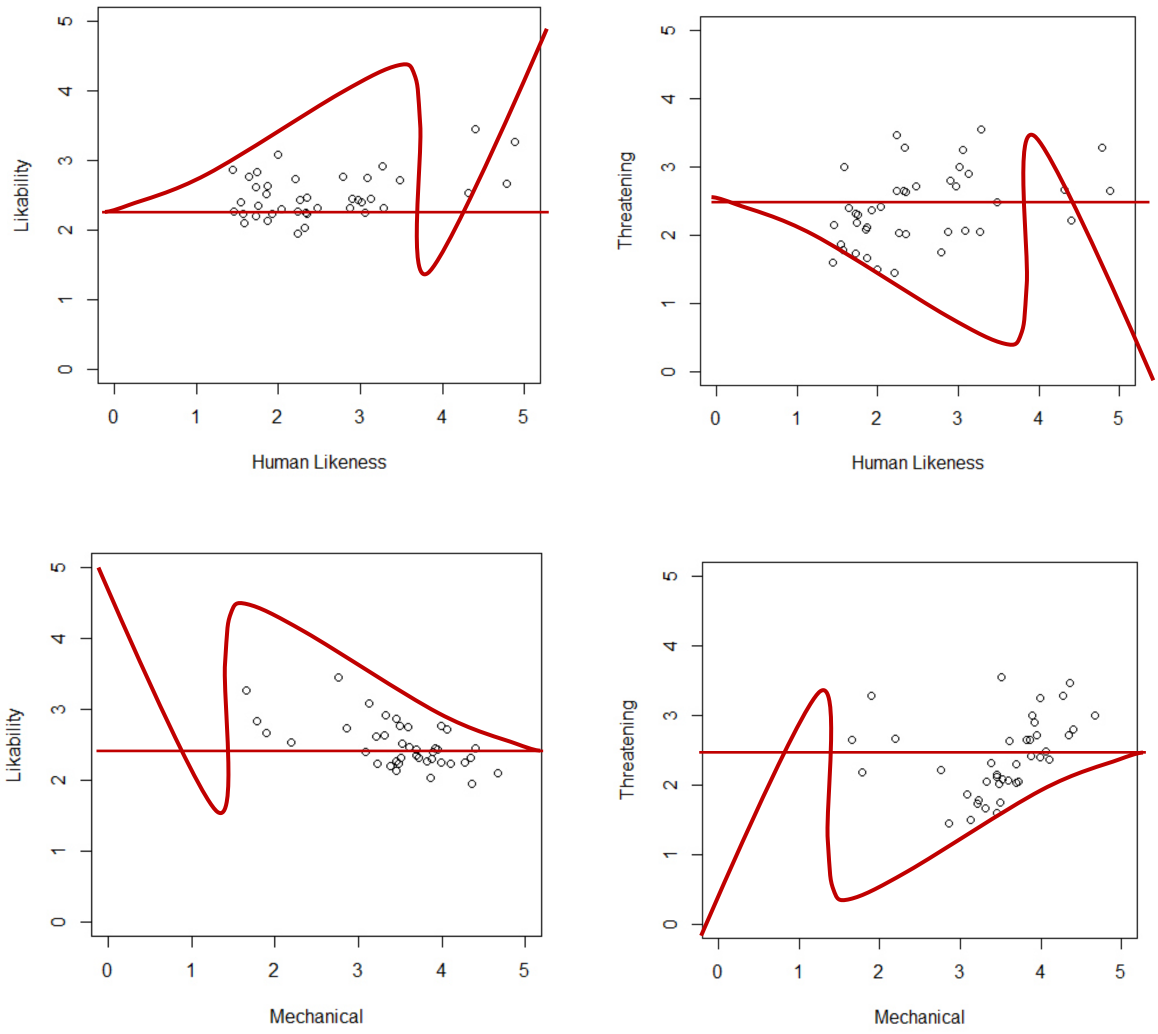


Figure 37: Scatterplots of the actual data presented with Mori's hypothetical graph of the uncanny valley effect

Also interesting is that the ratings for both *mechanical* and *human-like* do not spread over the whole scale, but indicate that the robots received rather average to high ratings on mechanical as well as on human-likeness. Indeed this picture set did not include robots which correspond to the classic industrial robot arm which might be located at the far left of the human-like scale. Moreover, there were no pictures of humans in the sample who might have received even lower mechanical ratings. Even the two Geminoid android robots, which actually are not easily distinguishable from humans when only seen in a picture received mean ratings on mechanical around 2 (on a 5-point Likert scale). However, this rating tendency could have been due to demand characteristics. As all participants were previously informed that they were about to evaluate robots, they might have inferred that since all pictures are robots and robots in general are regarded as mechanical, they should also rate the Geminoid robots as at least a bit mechanical. Furthermore, the data showed a strong tendency towards the center for the *likable* ratings. Either the robots really differ only marginally with regard to likability or this outcome is due to demand characteristics or a social desirability bias (Good-Subject effect: guess experimenter's hypotheses and confirm them; e.g. Nichols & Maner, 2008) where participants might have rated the robots generally overly likable. Implicit measures (e.g. reaction times) could be a useful addition to explicit ratings to investigate whether participants answered socially desirable. In contrast to the *likable* ratings, the *threatening* ratings showed more variance and might be the appropriate of examination of uncanny valley related effects by means of explicit evaluation.

2.4.3 Influence of gender and personality on the evaluation of robots

With regard to the influence of participants' gender, personality and robot anxiety on the evaluation of robots (***RQ4 & H4***), results showed no influence of participants' general interest in technology and their particular interest in robots, no influence of openness or neuroticism, and no influence of FFK self-efficacy. However, it was found that participants with higher scores in Robot Anxiety overall evaluated the robots as more threatening confirming ***H4***. With regard to the factor *overall-submissive*, people with strong beliefs in powerful others control (FKK) rated the robots overall as more submissive. People with higher values in "powerful other control" generally expect that important life events are majorly influenced by powerful others. A possible explanation for their higher ratings for *overall-submissive* could be that the robots presented are not perceived as powerful others in the sense of people who have the power to act or not to act in your favor. Particularly, because some of the robots have obviously limited interactive capabilities (e.g. are not mobile, have no arms). Furthermore, men evaluated the robots overall as more submissive and people with higher scores in Extraversion rated the robots less submissive. However, since the factor *submissive* achieved only low internal consistency, the impact of these results should not be overestimated. Moreover, although significant, the influences contributed only marginally to explained variance (below 8%). Altogether, there were some limited influences of gender, personality and robot anxiety on the evaluation of robots.

2.5 Limitations

The results of the exploratory factor analysis are restricted to the sample collected and generalization of the results can be achieved only if an analysis using different samples reveals the same factor structure. Moreover, the factor *submissive* showed only low internal reliability. The participants saw and evaluated all 40 robots in a within-subject design. Hence their answers might be affected by demand characteristics (e.g. Good-Subject effect: guess experimenter's hypotheses and confirm them; e.g. Nichols & Maner, 2008). Especially the strong tendency towards the center in *likable* ratings suggests a social desirability bias. In a follow-up study implicit measures will be combined with participants' explicit evaluations of the robots, in order to compensate for demand characteristics and social desirable answering behavior. In contrast to previous studies utilizing gradually varied stimulus material, the robots in this study varied greatly in their appearance. Thus, the stimulus material is less controlled than in other studies, because the differences between the robots were are idiosyncratic (robots were developed and designed by different people and for different purposes) and they not specifically designed to examine, for instance, a particular possible explanation of the uncanny valley effect (as in Burleigh et al., 2013).

3. Study 3b – Implicit attitudes towards robots assessed by an affective priming paradigm

The aim of this follow-up study is twofold. First, the evaluations of a smaller set of robots will be compared with the results of Study 3a in order to examine whether the evaluation factors (*likable, threatening, submissive,* and *unfamiliar*) and the ratings on these factors can be replicated. Moreover, whether ratings for human-likeness and mechanicalness differ between the two studies will be tested. Accordingly, the hypothesis is:

H1: Participants evaluations of the robots with regard to *human-likeness* and *mechanicalness* and the factors *likable*, *threatening*, *submissive*, and *unfamiliar* will not differ from those of Study 3a.

And second, implicit attitudes towards robots will be measured. As already mentioned previously, one limitation of Study 3a was that the participants evaluated all 40 robots in a within subject design and their answers might be affected by demand characteristics. Thus participants' explicit evaluations of the robots will be combined with measures on their implicit attitude towards these robots in order to compensate for demand characteristics or socially desirable answering behavior. This will be carried out according to the affective priming measurement techniques of Fazio et al. (Fazio et al., 1986; Fazio, 2001) which is based on the associative network structure of memory. This structure assumes a semantic propinquity between concepts and attitude objects of the same valence. Thus, a positive prime should reduce the participants' reaction time for evaluating a subsequent target as positive and a negative prime should reduce the participants reaction time for evaluating a subsequent target as negative, while reaction times for incongruent primes and targets increases. With this paradigm, participants' implicit attitudes towards the presented robots will be explored. Thus the following related research question is posed:

RQ1: What are participants' implicit attitudes towards the selected set of robots?

In addition, the relationship between implicit attitudes and explicit evaluations will be examined. If participants' evaluations were not biased a positive (negative) relationship between the implicit attitudes and explicit evaluations on the factor *likable* (*threatening*) can be assumed. Accordingly, it is hypothesized that:

H2: Participants' implicit attitudes towards the selected robots will correlate positively with their explicit evaluations of the robot on the factor likable.

H3: Participants' implicit attitudes towards the selected robots will correlate negatively with their explicit evaluations of the robot on the factor threatening.

As is Study 3a the influence of participants' gender, personality traits and technological affinity will be examined. Thus the following research question is proposed:

RQ4: Does the gender of the participants, their personality and/or their interest in technology influence the overall evaluation of the robots?

Moreover, in line with previous research, also Study 3a revealed a negative influence of robot anxiety on the evaluation of robots. Therefore, the influence of robot anxiety and participants' negative attitudes towards robots on the evaluation of robots will be examined. The related hypotheses are:

H4: Robot anxiety influences the overall evaluation of robots negatively.

H5: Participants' negative attitudes towards robots influence the overall evaluation of robots negatively.

3.1 Method

3.1.1 Stimulus material

As stimulus material twelve pictures of robots were used with two robots from each of the six clusters derived in Study 1. The robots were chosen according to their representativeness of the specific cluster; hence, those robots were chosen whose mean values in the six variables corresponded most strongly to the mean values of the cluster. The robots were Atom & Papero (cluster 1), ICat & Wakamaru (cluster 2), Geminoid HI-1 & Ibn Sina (cluster 3), Geminoid DK & HRP-4c (cluster 4), HRP3 & Justin (cluster 5) and Lucas & Mika (cluster 6).

3.1.2 Questionnaire

The questionnaire was basically the same as in Study 1. Participants rated each of the 12 robots on a 5-point Likert Scale with 16 items (weak, intelligent, unfamiliar, likable, uncanny, pleasant, natural, attractive, dominant, threatening, competent, familiar, submissive, harmless, strange, eerie) from "I agree" to "I do not agree at all". To be able to compare the ratings of the robots from Study 1 and Study 2 we calculated mean values for the four factors identified in Study 1: 1) *threatening* (threatening, eerie, uncanny, dominant, harmless (reverse), Cronbach's α = .92), 2) *likable* (pleasant, likable, attractive, familiar, natural, intelligent, Cronbach's α = .73), 3) *submissive* (incompetent, weak, submissive; Cronbach's α = .61) and

4) *unfamiliar* (strange, unfamiliar, Cronbach's α = .56). Again the first two factors *threatening* and *likable* achieved good internal reliability. The subscales *submissive* and *unfamiliar* received unsatisfying Cronbach's alphas. However, descriptive results will be reported for these two subscales.

Participants were further asked how human-like and how mechanical, respectively, they perceived the robots to be on a 7-point Likert-Scale ("not at all human-like (mechanical)" to "very human-like (mechanical)"). Moreover, participants were asked whether they noticed a specific positive or negative detail and to note this in a "free input box". Lastly, participants were asked to indicate whether they had seen the robot before.

3.1.3 Explanatory variables

As in the previous study the sub-dimensions extroversion (Cronbach's α = .87), neuroticism (Cronbach's α = .78), and openness (Cronbach's α = .76) of the 10-item *Big Five Inventory* (Rammstedt & John, 2007) were used as explanatory variables.

Further, peoples' anxiety towards robots was assessed using the *Robot Anxiety Scale* sub-dimension "Anxiety toward Behavioral Characteristics of Robots" (4 items, Cronbach's α = .78).

Also in this second study, participants filled in the *FKK Questionnaire for Competence and Control Orientations* (Krampen, 1991) with the sub-dimensions *Self-Concept of Own Competences* (Cronbach's α =.81), *Internality* (Cronbach's α =.53), and *Powerful Others Control* (Cronbach's α =.64). Internality was excluded from further analysis due to low internal reliability.

In addition to these previously used scales, participants filled in the *Negative Attitudes Towards Robots Scale* (Nomura et al., 2006). The NARS consists of 17 items rated on a 5-point Likert-Scale separated in three sub dimensions: *S1 Negative Attitudes toward Situations and Interactions with Robots* (6 items relating to anxieties toward operation and social influence, e.g. "I would feel very nervous just standing in front of a robot.", Cronbach's α = .36), *S2 Negative Attitudes toward Social Influence of Robots* (5 items, e.g. "I feel that if I depend on robots too much, something bad might happen.", Cronbach's α = .69), and *S3 Negative Attitudes toward Emotions in Interaction with Robots* (5 items, e.g. "If robots had emotions, I would be able to make friends with them.", Cronbach's α = .74). A higher score for NARS-S1 and NARS-S2 indicates a more negative attitude towards robots; conversely, a lower score indicates a more positive attitude. NARS-S3 is an inverse scale and a higher score indicates a more positive attitude; conversely, a lower score indicates a more negative attitude. The S1 subscale was excluded from further analysis due to low internal reliability.

3.1.4 Affective priming

In addition to the questionnaire data, data on implicit attitudes towards robots was gathered. This was carried out according to the affective priming measurement techniques of Fazio et al. (Fazio et al., 1986; Fazio, 2001). This method is based on the associative network structure of memory which assumes a semantic propinquity between concepts and attitude objects of the same valence. According to the theory, the presentation of the attitude object as a prime (e.g. prime “grief”) should activate any associated evaluations and, hence, facilitate a related judgment (e.g. target “ugly”). The paradigm developed by Fazio et al. (1986) used the computer-mediated subsequent presentation of stimuli to identify the valence of one stimulus (the prime). Participants were instructed to indicate whether the target word meant “good” or “bad” as quickly as possible. The focus was on the latency with which this judgment was made and, in particular, the extent to which it was facilitated by the presentation of an attitude object as a prime.

In the present study, pictures of the twelve aforementioned robots were used as primes. In addition, one positive and one negative picture of the *International Affective Picture System* (IAPS, Lang, Bradley & Cuthbert, 2008) were presented as distractors resulting in 14 primes in total. As targets 12 positive and 12 negative nouns (e.g. grief, love, war, etc.) were used which were previously tested with regard to their valence. Each of the 14 primes was presented 3 times with a positive target noun and three times with a negative target noun. This resulted in 84 trials in total. Irrespective of this constraint the target nouns were randomly assigned to the primes. The participants’ task was to indicate the target’s valence (positive or negative) as quickly as possible.

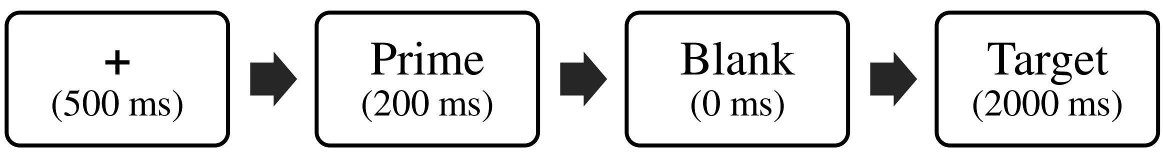


Figure 38: Sequence and time intervals of the stimulus presentation for one trial in the affective priming paradigm

Figure 38 shows schematically the time intervals of the stimuli presentation for one trial. At the beginning of each trial a white cross was presented for 500 milliseconds to direct participants' attention to the middle of the screen. Following this, the prime was presented for 200 milliseconds. The time interval between the presentation of the prime and the target – the stimulus onset asynchrony (SOA) - was set to 200 milliseconds. The target noun was subsequently presented for a time interval of 2000 milliseconds or until the participant's reaction. In the case of a wrong answer (e.g. evaluating war as a positive noun) participants were presented the word "failure" for 750 milliseconds. Participants with more than eight failures (10% of the trials) would have been excluded from the analysis of the implicit data. However, the highest number of failures was six. Based on Ratcliff (1993) all trials should be excluded from the analysis in which participants needed less than 300ms or more than 1000ms for their reaction. Thus, 3.29% of the trials were excluded.

3.1.5 Sample

In order to examine whether participants' evaluations of the robots differ between the two studies with regard to the factors *likable, threatening, submissive*, and *unfamiliar* a priori power analysis was conducted to determine the necessary sample size using G*Power3 software (Faul, Erdfelder, Buchner, & Lang, 2009). The calculation is based on an *independent t test* with 85% power, a large effect size of 0.8 (Cohen, 1988), and an alpha = .05. The resulting recommended sample size was 24 participants for each group (in this case the groups were Study 3a and Study 3b).

The sample consists of 35 university students (19 female, 16 male). Participants' ages ranged from 19 to 28 years (M = 22.24; SD = 2.57). All participants indicated that they did not own a robot. None of the participants was involved in research on robots. They had a moderate interest in technical topics (M = 4.57, SD = 1.89) and an average interest in robots (M = 3.48, SD = 1.47).

3.1.6 Procedure

Participants were recruited on campus and received extra credit for participation. Upon arrival participants filled in a questionnaire with demographic variables, the *Big Five*, and the *FKK* questionnaire. Subsequently participants were told that their next task was to evaluate nouns and match them to "good" or "bad" by pressing the relevant keys. They were instructed to concentrate on the words and not let the pictures distract them from their connotation task. In the subsequent questionnaire participants evaluated the robots as described above and lastly filled in the *NARS* and *Robot Anxiety Scale*.

3.2 Results

Statistical analyses were performed using IBM SPSS for Windows (Release 20.0; August 16th, 2011; SPSS Inc. IBM, Chicago). Kolmogorov-Smirnov tests were calculated to test for normal distribution. For normally distributed data parametric tests like *ANOVAs* and *t* tests were used for further analysis. Data deviating significantly from normal distribution were subject to non-parametric tests. An alpha level of .05 was used for all statistical tests.

3.2.1 Explicit evaluation of robots

In order to compare the evaluations of the robots in this second part of the study with the evaluation of the same robots in the first part of the study (***H1***), mean values for the factors *likable, threatening, submissive, unfamiliar* and the items *human-likeness* and *mechanicalness* were calculated. Independent t-tests were calculated to compare the ratings between the two groups (c.f. Tables 30-35). Examining the descriptive data, it can be observed that mean values in both studies were quite comparable for the robots in the six dimensions. There were only a few significant differences between the samples for single robots. With regard to *likable*, the robots Papero and Wakamaru received higher ratings in likable in the second study compared to the first study (cf. Table 30).

Table 30: Group differences for likable ratings of all 12 robots between the samples of Study 3a and Study 3b

			Likable					
	Study	*N*	*M*	*SD*	*df*	*t*	*p*	*d*
Geminoid HI-1	2	35	2.63	.72	184	-0.30	.763	-.05
	1	151	2.67	.76				
Geminoid DK	2	35	3.37	.60	62.8	0.54	.590	.10
	1	149	3.30	.77				
Autom	2	35	2.96	.62	184	1.49	.138	.30
	1	151	2.75	.76				
HRP-4c	2	35	3.58	.56	70.7	0.78	.440	.13
	1	149	3.49	.79				
ibnSina	2	35	2.41	.63	182	-1.21	.227	.24
	1	149	2.57	.70				
ICat	2	35	2.32	.56	62.5	0.87	.390	.14
	1	151	2.23	.72				
Papero	**2**	**35**	**3.17**	**.64**	**184**	**2.38**	**.018**	**.45**
	1	**151**	**2.86**	**.73**				
Justin	2	35	2.08	.46	66.9	-1.74	.086	.29
	1	151	2.24	.63				
Lucas	2	35	2.51	.64	178	1.30	.196	.25
	1	145	2.35	.66				
Mika	2	35	2.23	.45	84.5	-0.46	.644	.08
	1	145	2.28	.73				
Wakamaru	**2**	**35**	**2.70**	**.53**	**178**	**3.98**	**<.001**	**.79**
	1	**145**	**2.22**	**.67**				
HRP3	2	35	2.35	.55	179	0.18	.854	.03
	1	146	2.33	.66				

Table 31: Group differences for threatening ratings of all 12 robots between the samples of Study 3a and Study 3b

			Threatening					
	Study	*N*	*M*	*SD*	*df*	*t*	*p*	*d*
Geminoid HI-1	2	35	3.15	0.63	74.03	-0.97	.336	.16
	1	151	3.28	0.94				
Geminoid DK	2	35	2.73	0.67	67.12	0.34	.732	.06
	1	149	2.68	0.92				
Autom	2	35	2.17	0.37	90.29	1.36	.178	.21
	1	151	2.06	0.65				
HRP-4c	2	35	**2.59**	**0.65**	**182**	**2.45**	**.015**	**.48**
	1	149	**2.24**	**0.79**				
ibnSina	2	35	2.83	0.51	85.70	1.18	.241	.19
	1	149	2.70	.85				
ICat	2	35	**2.16**	**0.39**	**93.80**	**4.34**	**<.001**	**.66**
	1	151	**1.78**	**0.71**				
Papero	2	35	**1.35**	**0.39**	**184**	**-9.61**	**<.001**	**1.85**
	1	151	**2.08**	**0.40**				
Justin	2	35	3.52	0.62	71.28	1.76	.083	.30
	1	151	3.29	0.90				
Lucas	2	35	2.21	0.50	83.98	-0.31	.760	.04
	1	145	2.24	0.81				
Mika	2	35	2.57	0.66	178	1.04	.301	.21
	1	145	2.41	0.86				
Wakamaru	2	35	2.29	0.44	95.08	0.74	.463	.12
	1	145	2.21	0.80				
HRP3	2	35	3.32	0.54	97.57	-0.30	.762	.05
	1	146	3.36	1.00				

Table 32: Group differences for submissive ratings of all 12 robots between the samples of Study 3a and Study 3b

			Submissive				
	Study	*N*	*M*	*SD*	*df*	*t*	*p*
Geminoid HI-1	2	35	2.38	0.70	184	0.46	.648
	1	151	2.33	0.62			
Geminoid DK	2	35	2.23	0.67	182	-0.24	.807
	1	149	2.26	0.67			
Autom	2	35	2.94	0.66	184	1.20	.233
	1	151	2.79	0.68			
HRP-4c	2	35	2.45	0.55	182	-1.50	.135
	1	149	2.63	0.67			
ibnSina	2	35	2.91	0.63	182	0.93	.356
	1	149	2.79	0.70			
ICat	2	35	3.44	0.77	184	-1.87	.062
	1	151	3.72	0.81			
Papero	2	35	3.43	0.89	184	-0.88	.379
	1	151	3.55	0.73			
Justin	**2**	**35**	**1.61**	**0.55**	**184**	**-3.20**	**.002**
	1	**151**	**1.99**	**0.65**			
Lucas	2	35	3.05	0.65	178	-0.38	.706
	1	145	3.10	0.74			
Mika	2	35	2.85	0.70	178	-1.51	.132
	1	145	3.07	0.78			
Wakamaru	2	35	2.89	0.67	178	-1.27	.205
	1	145	3.07	0.81			
HRP3	2	35	1.80	0.49	179	-1.23	.219
	1	146	1.95	0.68			

Table 33: Group differences for unfamiliar ratings of all 12 robots between the samples of Study 3a and Study 3b

			Unfamiliar				
	Study	*N*	*M*	*SD*	*df*	*t*	*p*
Geminoid HI-1	2	35	3.06	1.17	184	1.43	.155
	1	151	2.77	1.03			
Geminoid DK	2	35	2.37	0.83	182	0.89	.375
	1	149	2.21	0.96			
Autom	2	35	2.74	0.89	184	-1.16	.248
	1	151	2.92	0.80			
HRP-4c	2	35	2.59	0.83	182	0.89	.373
	1	149	2.44	0.90			
ibnSina	**2**	**35**	**3.20**	**0.84**	**182**	**2.19**	**.030**
	1	**149**	**2.87**	**0.80**			
ICat	2	35	3.51	0.89	184	0.94	.350
	1	151	3.36	0.87			
Papero	2	35	2.84	0.90	184	-1.61	.109
	1	151	3.12	0.92			
Justin	2	35	3.57	0.89	184	-0.39	.698
	1	151	3.64	0.88			
Lucas	2	35	3.53	0.87	178	-1.52	.130
	1	145	3.78	0.86			
Mika	2	35	3.74	0.74	178	-0.12	.905
	1	145	3.76	0.88			
Wakamaru	2	35	3.10	0.88	178	-1.88	.061
	1	145	3.41	0.87			
HRP3	2	35	3.46	0.72	179	0.82	.414
	1	146	3.33	0.88			

Table 34: Group differences for human-likeness ratings of all 12 robots between the samples of Study 3a and Study 3b

			Human-likeness				
	Study	*N*	*M*	*SD*	*df*	*t*	*p*
Geminoid HI-1	2	35	4.83	0.62	184	0.31	.755
	1	151	4.79	0.57			
Geminoid DK	**2**	**35**	**5.00**	**0.00**	**148**	**2.71**	**.008**
	1	**149**	**4.89**	**0.51**			
Autom	2	35	3.03	0.82	184	-0.28	.783
	1	151	3.08	1.02			
HRP-4c	2	35	4.51	0.51	182	0.94	.348
	1	149	4.40	0.66			
ibnSina	2	35	4.34	0.94	182	0.12	.902
	1	149	4.32	0.88			
ICat	2	35	1.63	0.84	184	0.36	.720
	1	151	1.57	0.88			
Papero	2	35	1.43	0.61	184	-0.06	.950
	1	151	1.44	0.75			
Justin	**2**	**35**	**2.77**	**0.91**	**184**	**2.36**	**.019**
	1	**151**	**2.33**	**1.01**			
Lucas	**2**	**35**	**1.26**	**0.44**	**84**	**-1.99**	**.050**
	1	**145**	**1.45**	**0.73**			
Mika	2	35	1.54	0.66	178	-1.15	.253
	1	145	1.72	0.84			
Wakamaru	**2**	**35**	**2.43**	**0.85**	**178**	**3.57**	**.000**
	1	**145**	**1.87**	**0.83**			
HRP3	2	35	2.97	0.95	179	-0.46	.644
	1	146	3.06	1.05			

Examining the ratings for the factor *threatening*, results show significant differences for three robots – HRP-4c, ICat and Papero. HRP-4c and ICat received higher ratings in threatening in the second study compared to the first study and Papero received a lower mean rating in the second study compared to the first (cf. Table 31).

With regard to the factor *submissive*, only one significant difference was found. Justin received a lower mean rating in the second study compared to the first (cf. Table 32).

For the factor *unfamiliar* also only one significant difference was found. The android robot ibnSina received a higher mean rating in the second study compared to the first (cf. Table 33).

With regard to the *human-likeness* ratings, results revealed three significant differences. Geminoid DK, Justin and Wakamaru received a higher mean rating in the second study compared to the first and Lucas received a lower mean rating (cf. Table 34).

Regarding the ratings on *mechanicalness* results revealed a number of significant differences. ICat, Papero, Justin, Lucas, Mika were all rated as more mechanical in Study 2 compared to Study 1. The robots Wakamaru and Geminoid DK were rated as significantly less mechanical in the second study compared to the first (cf. Table 35).

Table 35: Group differences for mechanicalness ratings of all 12 robots between the samples of Study 3a and Study 3b

			Mechanicalness				
	Study	*N*	*M*	*SD*	*df*	*t*	*p*
Geminoid HI-1	2	35	1.69	0.99	184	-1.00	.318
	1	151	1.90	1.18			
Geminoid DK	**2**	**35**	**1.31**	**0.76**	**81**	**-2.07**	**.042**
	1	**149**	**1.65**	**1.22**			
Autom	2	35	3.83	0.89	52	1.38	.172
	1	151	3.60	0.92			
HRP-4c	2	35	2.86	0.97	61	0.51	.609
	1	149	2.76	1.20			
ibnSina	2	35	2.17	1.01	182	-0.08	.940
	1	149	2.19	1.19			
ICat	**2**	**35**	**4.14**	**1.12**	**184**	**3.87**	**.000**
	1	**151**	**3.23**	**1.28**			
Papero	**2**	**35**	**4.23**	**1.00**	**59**	**3.91**	**.000**
	1	**151**	**3.46**	**1.20**			
Justin	**2**	**35**	**4.71**	**0.62**	**72**	**3.39**	**.001**
	1	**151**	**4.28**	**0.91**			
Lucas	**2**	**35**	**4.29**	**1.02**	**64**	**4.06**	**.000**
	1	**145**	**3.46**	**1.30**			
Mika	**2**	**35**	**4.26**	**0.70**	**98**	**5.47**	**.000**
	1	**145**	**3.38**	**1.30**			
Wakamaru	**2**	**35**	**4.40**	**0.69**	**82**	**6.36**	**.000**
	1	145	3.45	1.12			
HRP3	2	35	4.23	0.65	179	1.42	.156
	1	146	3.99	0.95			

A post hoc power analysis was conducted again using G*Power3 (Faul et al., 2009) with the actual sample size of 35 participants and an *independent t-test* as a baseline. The recommended effect sizes used for this assessment were as follows: small ($f^2 = .20$), medium ($f^2 = .50$), and large ($f^2 = .80$; Cohen, 1988). The alpha level used for this analysis was $p < .05$. The post hoc analyses revealed the statistical power for this study was .28 for detecting a small effect, whereas the power was .84 for the detection of a moderate one and exceeded .99 for the detection of a large effect size. Thus, there was more than adequate power (i.e., power * .80) at the moderate to large effect size level, but less than adequate statistical power at the small effect size level.

3.2.1 Implicit attitudes towards robots

To explore participants' implicit attitudes towards the robots presented (***RQ1)*** mean values were calculated for both the three positive and negative trials in the affective priming paradigm. Differences were calculated (referred to as diff-prime in Table 36) by subtracting the mean value of the positive trials from the mean value of the negative trials. With regard to the affective priming task, results show that only three robots received negative diff-primes: HRP-4c, ibnSina and Justin. While the negative results for ibnSina and Justin are quite intuitive, because these robots are also among the most threatening and least likable ones, the negative diff-prime for HRP-4c is surprising given its rather high likability ratings in both studies. The other robots, Geminoid HI-1, Geminoid DK, Atom, Icat, Lucas, Mika, Wakamaru, HRP3 received positive diff-Primes. However, the prime values range between -8.46 and +27.28, but the negative control received a value of -50.69 and the positive control a value of 41.69. Thus, comparing the positive and negative control pictures with the primes showed that the prime pictures did not even come close to the positive and negative diff-prime values, respectively. Given the overall mean value of the diff-primes (M = 8.77, SD = 27.09) and the range of the control pictures diff-prime values, it seems that the diff-prime values of the primes also show a strong central tendency. Participants reveal neither particularly strong positive nor strong negative implicit attitudes towards the robots presented.

Table 36: Mean values and standard deviations for diff prime for all 12 robots in the affective priming experiment

			Diff Prime	
		N	M	SD
Cluster 3	Geminoid HI	35	21.33	98.40
	Ibn Sina	35	-2.34	93.19
Cluster 4	Geminoid DK	35	1.43	115.94
	HRP-4c	35	-8.46	89.78
Cluster 1	Atom	35	21.60	103.46
	Papero	35	9.84	85.66
Cluster 2	ICat	35	16.35	83.45
	Wakamaru	35	3.65	106.58
Cluster 5	Justin	35	-0.02	91.96
	HRP3	35	27.28	94.41
Cluster 6	Mika	35	11. 22	85.51
	Lucas	35	7.13	97.40
Control positive		35	41.69	(78.28)
Control negative		35	-50.69	(95.42)

3.2.1 Correlation analyses

To test the hypotheses that ratings on *likable* (***H2***) and *threatening* (***H3***) correlate respectively with the diff-Prime values positively or negatively, correlation analyses were conducted which did not show any significant correlations between the variables.

The data will be visually inspected to further examine the relationship between likable, threatening and the implicit attitudes measured by the diff-primes. Participants' ratings for *likable* (red dots) and the diff-prime values (purple squares) for all robots are plotted against the human-likeness dimension and depicted in Figure 39. The difference between the likability rating and the diff-prime for each robot is indicated by an arrow. Obviously, the amount of the differences varied greatly from robot to robot. The same procedure was executed for the threatening ratings. Results are depicted in Figure 40.

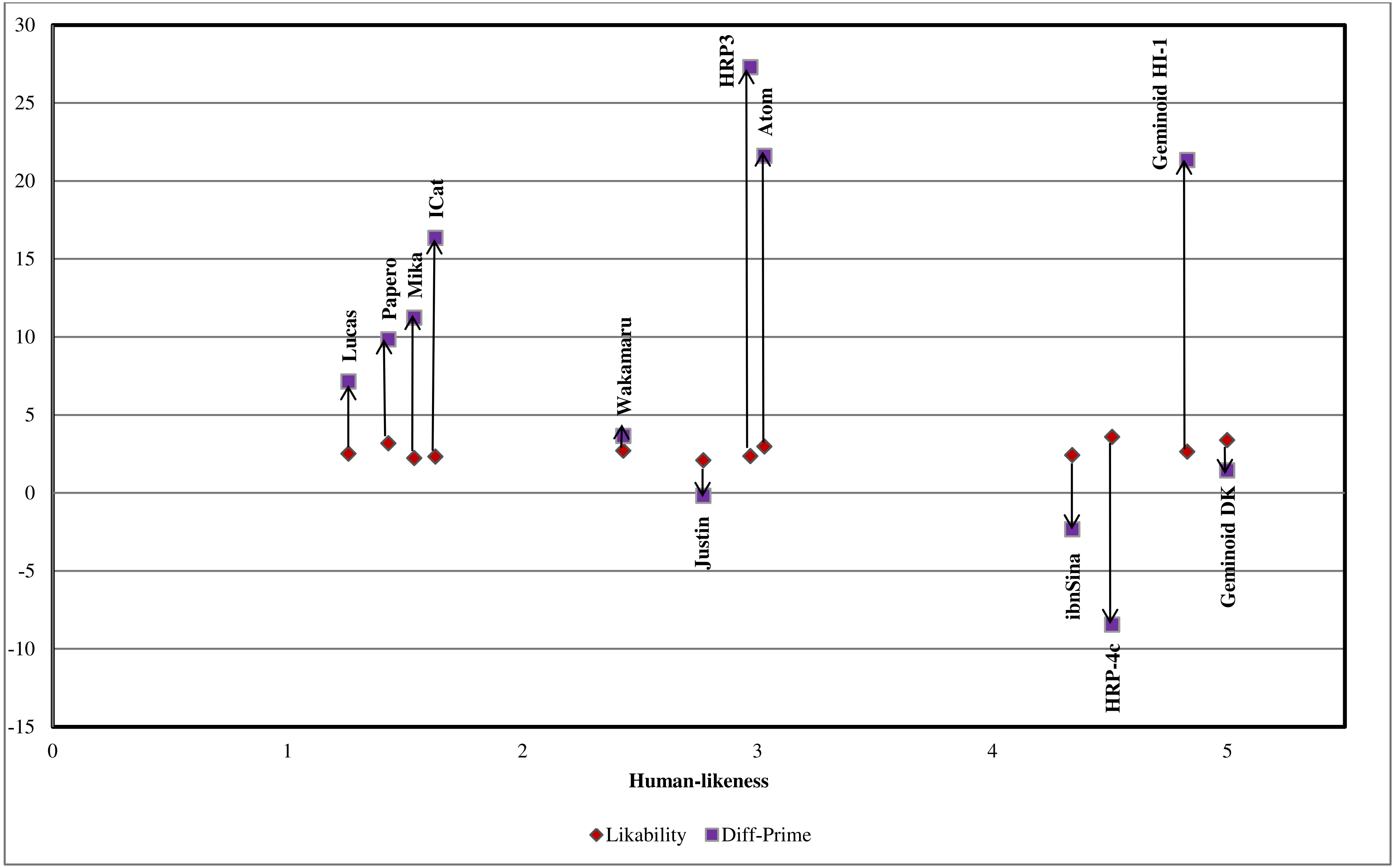


Figure 39: Relationships of participants' likable ratings and the diff-prime values for all twelve robots

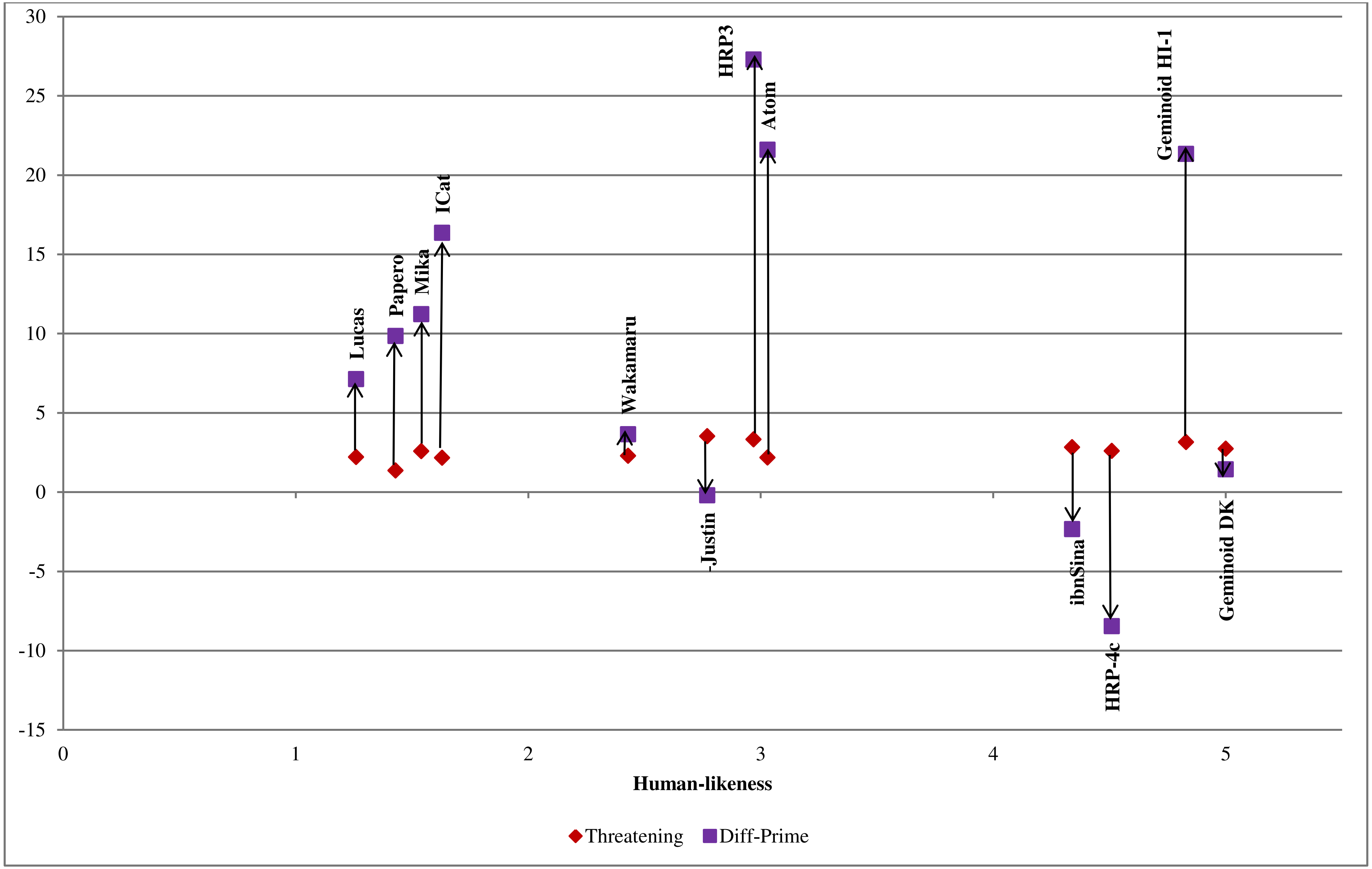


Figure 40: Relationships of participants' threatening ratings and the diff-prime values for all twelve robots

3.2.2 Regression analyses

Furthermore, the participants' gender, personality and characteristics were examined to establish whether they can predict the overall evaluation of the robots (see ***RQ4, H4 & H5***). For this purpose, mean values for each participant with regard to their overall ratings on the four person perception factors were calculated. Subsequently, regression analyses were conducted with *overall-likable, overall-threatening,* and *overall-Diff-Prime* as dependent variables and the following predictors: gender, interest in technology, interest in robots, the sum scores of the BIG FIVE subscales extraversion, openness and neuroticism, the sum scores of the FKK subscales powerful others control and self-efficacy and the sum score of the Robot Anxiety Scale.

Results show that participants' general interest in technology was not predictive. The *FFK* subscales (self-efficacy, powerful others control), the *Big Five* subscales (extroversion, openness, neuroticism), and the *Robot Anxiety Scale* (H4) were also not predictive.

With regard to the factor *overall-threatening*, the results show that participants with increased interest in robots rated the robots as more threatening. Interest in robots significantly predicted threatening scores, β= .37, $t(33) = 2.32$, $p = .027$, and also explained a significant proportion of variance in threatening scores, $R^2 = .14$, $F(1, 34) = 5.37$, $p = .027$.

With regard to the factor *overall-likable*, the results show that those participants with a more positive attitude towards robots with emotions (Negative attitudes towards robots – S3 subscale) rated the robots as more likable. S3 significantly predicted likable scores, β= .37, $t(33) = 2.32$, $p = .027$. S3 also explained a significant proportion of variance in likable scores, $R^2 = .14$, $F(1, 34) = 5.37$, $p = .027$. Furthermore, men rated the robots as more likable. Gender predicted likable scores, β= .39, $t(33) = 2.39$, $p = .023$; and gender also explained a significant proportion of variance in likable scores, $R^2 = .15$, $F(1, 34) = 5.73$, $p = .023$.

No valid regression models emerged for *overall-Diff-Prime*.

3.3 Discussion

The aim of this study was twofold. First, the evaluations of this smaller set of robots were compared with the results of the first part of the study to see whether the evaluation factors (*likable, threatening, submissive, unfamiliar*) and the ratings on these factors could be replicated. And second, participants' explicit evaluations of twelve robots were combined with measures on their implicit attitude towards these robots.

With regard to the first question, results show that the evaluations of the twelve robots on the factors *likable, threatening, unfamiliar*, and *submissive* overall correspond to those from Study 3a except for a few significant differences between the samples for single robots. However, the factors *unfamiliar* and *submissive* achieved rather low internal reliability and results should not be overestimated. Also the ratings for *human-likeness* were quite comparable between the two studies. With regard to *mechanicalness*, however, a higher number of differences emerged mostly in the direction that mechanical robots were rated as even more mechanical and not that mechanical robots were rated as even less mechanical. The post-hoc power analysis revealed that the power in this experiment was adequate to find medium or large effects, but too low to find small effects.

With regard to participants' implicit attitudes towards robots, it was found that participants revealed neither particularly strong positive nor strong negative implicit attitudes towards the robots presented. Likewise, for the participants' explicit evaluation of the robot in terms of likability they also revealed a strong central tendency with regard to implicit attitudes. To test the hypothesis that ratings on likable and threatening correlate positively or negatively, respectively, with the Diff-Prime values correlation analyses were conducted which did not show any significant correlations between the variables. A visual inspection of the likable ratings and diff-prime values for each robot shows that the amount of the differences between the ratings varied greatly from robot to robot without any particular pattern observable.

Furthermore, it was examined whether the participants' gender, their personality and characteristics can predict the overall evaluation of the robots. Results showed that participants with a greater interest in technology consistently rated the robots as more threatening. Participants with a more positive attitude towards robots with emotions consistently rated the robots as more likable. Moreover, men rated the robots as more likable.

4. Discussion

The aim of this third study was to systematically investigate how different robot appearances are perceived. The few previous studies which systematically investigated robot appearances (e.g. DiSalvo et al., 2002; Powers & Kiesler) were limited to the heads of humanoid robots, neglecting non-humanoid robots and the robots' bodies. Uncanny valley related studies concentrated more on the emulation of the uncanny valley graph and thus only looked into perceived human-likeness and perceived familiarity of the robots. These studies often used non-standardized material making it hard to draw general conclusions. Therefore, a new approach was used to systematically investigate robot appearances. In two subsequent studies standardized pictures of robots were evaluated using explicit (Study 3a & Study 3b) and implicit measures (Study 3b). In the following the studies will be briefly summarized and results will be discussed on the basis of concepts important for the uncanny valley.

In the first part of the study a large set of pictures of actual available robots has been evaluated with regard to items related to person perception and uncanny valley phenomenon. The resulting dimensions for the evaluations were the perceived *human-likeness* and *mechanicalness* of the robots and their perceived *threatening* appearance, *likable*, *submissiveness*, and *unfamiliarity*. By the use of a cluster analysis six clusters of robots which had been evaluated similarly on the above mentioned dimensions were identified and examined with regard to characteristics of appearance which were shared among the robots in the specific cluster. Indeed, for every cluster certain design characteristics could be identified. The resulting clusters (with a briefly summarized characterization) are the following:

1. likable, small, playful robots (baby-scheme, small)
2. submissive, colorful, unusual shaped robots (toy-like appearance, small)
3. more threatening androids (Arabic & Asian-looking male androids)
4. more likable androids (Caucasian male android, Asian female android)
5. threatening mechanical robots (bi-pedal robots, bulky, tall)
6. unfamiliar futuristic robots (medium height, unusual shapes, often on wheels)

In the second part of this study (Study 3b) two robots from each of the six clusters were chosen and evaluated by participants with regard to the same dimensions used in Study 3a (*likable, threatening, submissive, unfamiliar, human-likeness, mechanicalness*). Overall, participants' explicit evaluations of the twelve robots in Study 3b did not differ greatly from those in Study 3a. Moreover, participants' implicit attitudes towards these twelve robots were measured by means of an affective priming paradigm.

4.1 Perceived human-likeness & mechanicalness

Within the uncanny valley hypothesis and especially in Mori's hypothetical graph of the uncanny valley effect the x-axis is the dimension of human-likeness. Most previous work suggests that researchers regard the dimension of human-likeness first and foremost as a matter of appearance (Bartneck et al., 2007; MacDorman, 2006; Riek et al., 2009), because experimental manipulation of this dimension mainly concentrated on manipulation of visual material (e.g. Burleigh et al., 2013; Cheetham et al., 2013; Cheetham et al., 2011; Hanson et al., 2005; Hanson, 2006; Lay, 2006; MacDorman & Ishiguro, 2006; Riek et al., 2009; Saygin et al., 2012; Seyama & Nagayama, 2007; Tinwell & Grimshaw, 2009) instead of, for instance, behavior which certainly also contributes to the perception of human-likeness. However, behavior was less often addressed in experimental uncanny valley related research and was mostly examined with android robots (Bartneck et al., 2009; Minato et al., 2004; Minato et al., 2006; Shimada et al., 2006; Shimada & Ishiguro, 2008; Thompson et al., 2011). Hence, appearance is a very important factor in partly constituting human-likeness. However, studies systematically examining the relationship of human-likeness and appearance were limited to a special type of robot (heads of humanoid robots, DiSalvo et al., 2002; Powers & Kiesler, 2006) or used gradually morphed pictures instead of actually existing robots (e.g. Burleigh et al., 2013; MacDorman & Ishiguro, 2006; Seyama & Nagayama, 2007). In this study a large set of standardized pictures of actual robots were evaluated with regard to perceived human-likeness of the robots.

As can be intuitively expected, the two android clusters (cluster 3 & 4) were rated as most human-like by far. Following the cluster five (threatening, bi-pedal robots, bulky, tall) received medium ratings in human-likeness. Despite the fact that robots in cluster five throughout had a more human-like figure (torso, head, arms, hands, and legs), this cluster was rated only slightly more human-like than cluster one or two. Moreover, these robots received the highest ratings in mechanical. This is to some extent in contrast to the interview results were precisely features such as having a head, torso, arms and legs were associated with human-like appearance. Moreover, this also contradicts the general assumption in Mori's hypothesis that humanoid robots are also perceived as being very human-like, because the ratings were still quite low (with a mean of 2.7 in a range from 1 to 5). A possible explanation would be that the positive effect of a human-like figure has been undermined by the overall more bold and bulky appearance of the robots in cluster 5. However, when depicting the robots along the human-likeness dimension, it becomes clear that robots with a human-like figure (head, torso, arms, and legs) were rated more human-like, than those without human-like figures (cf. Figure 41). Interestingly, participants' ratings on mechanicalness and human-likeness were not spread over the whole scale, but the robots received rather medium to high ratings on mechanical as well as on human-likeness. This could be due to the fact that the picture set did not include, for instance, mobile robots and industrial robot arms, nor did it include pictures of humans. Thus, the scale did not reflect the whole range from industrial robot arm to healthy human.

Figure 41: Perceived human-likeness: Papero, Lucas, Asoy, ICAT, PR2, Phope, Mika, Riba, Leonardo, Olivia, Luna, Wakamaru, RobovieMR2, Kismet, Autom, Emmys, Cosmobot, Twendyone, Robonova, Snackbot, Robosapien, Justin, Popo, Ri-man, Armar, Nao, dynamoid, Wabian, Hrawang, REEM-1, HRP3, Atom, HRP2, Asimo, REEM-1390, Kobian, ibnSina, HRP-4c, Geminoid HI-1, Geminoid DK

In contrast to DiSalvo et al. (2002) and Powers et al. (2006) who examined the influence of facial features, the present results do not suggest that having facial features particularly contributed to perceived human-likeness, since robots at all stages along the human-likeness dimension exhibited facial features.

Correlation analyses found that overall human-likeness and mechanicalness were negatively correlated. However, no correlation was found for single robots and results showed that cluster one and cluster two were rated both low in human-likeness and low in mechanicalness, while cluster five was rated high in mechanical and rather high in human-likeness. Moreover, when examining the relationship between human-likeness and mechanicalness and the uncanny valley related responses measured by the robots ratings on Likability and Threatening (cf. Section V.2.3.6), it was found that different predictive models (linear vs. quadratic) emerged for human-likeness and mechanicalness. Altogether, the recommendation is to further use mechanicalness and human-likeness as two distinct dimensions instead of treating them as the extremes of one dimension.

4.1 Perceived unfamiliarity

Regarding *unfamiliarity*, robots in cluster six (unfamiliar, futuristic robots) were significantly more unfamiliar than all other groups. Moreover, cluster two (colorful, unusually shaped robots) was rated as unfamiliar. In contrast, the two android clusters were rated most familiar; hence participants obviously understood familiarity in terms of *familiar according to the human stereotype*. In the interviews (Study 1) participants' robot stereotype was depicted as that of a humanoid robot which are best represented by robots in cluster five (mechanical, bi-pedal robots, bulky, tall). However, with regard to unfamiliarity, this cluster was not rated most unfamiliar, but cluster six with robots that have relatively unusual forms (futuristic shapes). These results bolster the critique that familiarity (or in this case unfamiliarity) is not adequate to measure an uncanny valley related response, because of its ambiguousness (cf. Bartneck et al., 2007; Bartneck et al., 2009).

Furthermore, results showed that mechanicalness and human-likeness predicted *unfamiliar* ratings. Higher perceived human-likeness resulted in higher familiarity and higher perceived mechanicalness resulted in higher perceived unfamiliarity.

4.1 Perceived likability

With regard to Likability, the robots in three clusters were perceived as rather likable. The android cluster four (Asian female android & Caucasian male android) were most likable by far, followed by cluster one (likable, small, playful robots with baby-scheme) and the other android cluster in the third rank. However, overall the ratings for likable showed a strong tendency towards center. Given the difference between the two androids clusters, it seems that mere human-like appearance does not necessarily determine likability. Participants' statements in the interviews (Study 1) revealed that Geminoid HI-1 was often negatively perceived because of its stern facial expression, whereas HRP-4c was often perceived as likable because of its obvious female gender. Indeed the four android robots varied in gender, race and culture which might have caused in- or out-group biases in likability ratings. These conclusions remain, however, speculative, because neither gender nor ethnicity had been systematically varied in this limited stimulus set of only four android robots. With regard to the non-android robots facial features according to the baby-scheme seem to have a positive effect on likable ratings, although statements in the interviews were quite mixed with regard to this topic. The baby-scheme was often recognized for both robots, but not particularly positively evaluated.

Moreover, compared to the android robots (cluster 3&4) the humanoid robots (cluster 5) were rated lower on *likable.* This stands in contrast to the general assumption about the uncanny valley hypothesis that humanoid robots elicit higher affinity and that android robots were located somewhere in the uncanny valley.

Furthermore, results showed that mechanicalness and human-likeness predicted *likable* ratings. Perceived human-likeness resulted in higher likability and perceived mechanicalness resulted in lower likability.

4.1 Perceived threatening & submissiveness

With regard to *threatening* and *submissive*, results showed that the android robots and the bi-pedal robots in cluster five were rated as *threatening*. In the interviews (Study 1) participants frequently stated that they feared that robots capable of bi-pedal upright walking were potentially dangerous, because they might "come after them". Furthermore, the robots in these three clusters were also the tallest robots in the set. Height was also mentioned in the interviews as being influential in the perception of the dangerousness of robots. Thus, it is not surprising that robots in those clusters which were rated high with regard to submissiveness (cluster 1 & 2) either lacked mobility or were rather small compared to the rest of the robots in the set.

Furthermore, the regression analyses showed that human-likeness but not mechanicalness predicted *threatening* by means of a linear regression. However, mechanicalness predicted Threatening by means of a quadratic function (see below). Furthermore, both - human-likeness and mechanicalness - served as predictors for s*ubmissive*.

4.1 Implicit evaluation of robots

With regard to participants' implicit attitudes towards robot measurement by means of an affective priming paradigm, results showed that participants revealed neither particularly strong positive nor strong negative implicit attitudes towards the robots presented. Similar to the likability ratings there was a strong central tendency observable with regard to implicit attitudes. In addition, participants' explicit evaluation (likable & threatening) did not correlate with their implicit attitudes towards robots. Within the affective priming paradigm the effect of automatic activation of evaluative processes for a given prime is used, because automatic activation of these processes results in an encoding advantage and response facilitation or competition. If prime and target are evaluatively congruent, subsequent responses are facilitated and if prime and target are incongruent subsequent responses are inhibited.

However, Fazio (2001) describes certain mechanisms mediating the affective priming effect, one of which is the “strength of the object-evaluation association determines the accessibility of the attitude from memory and, hence, the likelihood that the associated evaluation will be activated automatically upon the individual’s exposure to the attitude object.” (p.122). Hence, there exist strong and weak primes with higher or lower likelihood of eliciting automatic attitude activation. Since robots are not everyday objects, participants might not have formed very strong attitudes about robots. In line with this it has been shown that the moderating effect of associative strength can itself be moderated by the extent to which attitudes toward the primes have been considered recently (Bargh, Chen, & Burrows, 1996). Then robots would be weak primes with a low likelihood of eliciting associated evaluations. Moreover, it could be that participants indeed have an overall mildly positive attitude towards robots, but that the robots presented were rather seen as a coherent category of objects with the same evaluative association. Again, since robots are not everyday objects, participants might not have formed distinct attitudes towards different kinds of robots. In further research, the category of robots could be compared to other categories related to the uncanny valley such as machines and humans.

4.1 Reproducing the uncanny valley

The uncanny valley theory predicts a nonlinear relationship between human-likeness and some uncanny valley related response on the side of the user. Examining Mori’s graph the depicted curve can best be described by a cubic function. As summarized earlier the common procedure to probe for the uncanny valley function is to plot ratings for human-likeness and the uncanny valley related response (e.g. subjectively perceived uncanniness or eeriness; e.g., Hanson, 2006; Hanson et al., 2005; Lay, 2006; MacDorman, 2006; MacDorman & Ishiguro, 2006; MacDorman et al., 2009; Tinwell & Grimshaw, 2009). While most authors only present descriptive results, Burleigh et al. (2013) tested whether linear, quadratic or cubic models fit best to the data obtained within their study. In a similar approach the present data from Study 3a were analyzed. In contrast to Burleigh et al., not only human-likeness but also mechanicalness ratings were used to predict participants’ responses. Similarly to Burleigh et al. *likability* and *threatening* ratings were considered for analysis, because of Ho and MacDorman’s (2010) assumption that “shinwa-kan” (affinity/likability) and “bukimi” (eeriness/threatening) were distinct dimensions. Results showed that, similar to Burleigh et al.’s results, the data in this study could not be explained by a cubic function as would be suggested by the uncanny valley graph proposed by Mori, but rather by linear or quadratic relationships. Results overall suggested a linear relationship between human-likeness and *threatening* (bukimi) and a linear or quadratic relationship between human-likeness and *likable* (shinwa-kan). Furthermore, results suggested a linear relationship for mechanicalness and *likable*. Only the relationship between mechanicalness and *threatening* was clearly not linear but quadratic. According to the quadratic model very mechanical robots and least mechanical robots (android robots) are perceived as most threatening, while medium mechanical robots are least threatening. Since the two dependent variables (likable and threatening) were explained best by different (linear versus quadratic) models the assumption of Ho and MacDorman (2010) that they are distinct dimensions is supported. With regard to the uncanny valley hypothesis these results imply that the graph itself would be misleading, because it would integrate participants' responses on two dependent variables in one dependent variable, thereby distorting the real relationship between human-likeness and affinity or eeriness, respectively. Thus, the recommendation would be to include a measure for affinity and a measure for "bukimi" or eeriness in further studies investigating the uncanny valley.

5. Limitations

Altogether, the two reported studies in this section were subject to some limitations. As already mentioned in section V.2.5 the results of the exploratory factor analysis were restricted to the sample collected and generalization of the results can be achieved only if analysis using different samples reveals the same factor structure. Although the participants ratings for a subset of twelve robots in Study 3b overall corresponded to the ratings in Study 3a, a replication with the large set of robots and a higher number of participants would be necessary. Furthermore, the factor *submissive* showed only low internal reliability in both studies and the factor *unfamiliar* received low internal reliability in Study 3b. Since a low number of items within a factor can deflate reliability scores, additional items relating to familiarity might be needed in further studies, to reliably measure this factor.

Likability ratings as well as affective priming data showed strong central tendencies. With regard to likability, this might be due to demand characteristics or socially desirable answering behavior. Another explanation would be that the robots used in this study did not reflect the whole human-likeness scale depicted by Mori, because the sample did not include pictures of healthy humans or, for instance, industrial robots. With regard to the affective priming paradigm it might be the case that participants might not have formed very strong attitudes about robots, because robots are not everyday objects and thus robots could be regarded as so-called weak primes. Moreover, robots could be perceived as one class of attitude objects for which participants had an overall mildly positive attitude. Participants might not have formed distinct attitudes towards different kinds of robots.

Furthermore, the pictures used in this study were not gradually varied stimulus material and thus were less controlled than in previous studies. However, the sample comprises actually existing robots making the results relevant to developers and designers of robots.

VI. STUDY 4: TESTNG EXPLANATIONS FOR NEGATIVE EVALUATIONS OF ROBOTS

1. Introduction

The previously reported studies examined a variety of aspects important to the uncanny valley, for instance, the influence of robotic movement on participants' perception of robots or their actual behavior (Study 1 & 2) and the importance of the aspects of human-likeness and appearance with regard to the perception and evaluation of robots (Study 1 & 3). The results contribute to a deeper understanding of how different robots are perceived and evaluated and gave first insights into the underlying mechanisms of why they are perceived and evaluated as such. In this fourth study, the testing of explanatory approaches for the uncanny valley effect will be focused on.

The investigation will be based on the hitherto gathered results and concentrate on the aspect of appearance, i.e. human-likeness. According to Mori's uncanny valley hypothesis, uncanny valley related responses can occur for still as well as for moving objects and might be more extreme for the latter ones. Although movement is certainly a highly influential factor, there are still open questions when solely regarding the aspect of appearance. In addition, investigating the effects of robotic movements often entails restrictions with regard to the variety of stimulus material that can be used and the standardization of this stimulus material. While it is manageable to get a larger set of pictures of humans and robots, it is quite hard to receive or produce videos of different robots, especially if the videos have to follow certain guidelines in order to compare them. Moreover, showing videos instead of pictures of a large set of stimuli also lengthens the experimental paradigm. Considering all these arguments, it was decided to concentrate on the aspect of appearance and base the study partly on the stimulus material used in Study 3.

The uncanny valley effect has often been described as some kind of negative emotional reaction. In Study 1 participants were explicitly asked for their emotional reactions towards the robots presented. Results showed that their answers were very mixed – some experienced positive, some negative emotions, some did not experience emotions. In addition, some participants had difficulties to express their emotional state properly. To examine whether the uncanny valley indeed is an emotional reaction alternative methodological approaches to investigate emotional reactions are necessary. The explanations offered for the uncanny valley response often refer to perceptual or cognitive processes which are difficult to measure by self-report, because they might not be accessible to the individual by introspection such as experiences of cognitive dissonance caused by increased brain activity due to additional processing effort for certain stimuli. Other explanations might be accessible by introspection, but are socially not desirable to report, like the experience and report of disgust when looking at a certain picture. Thus, this study will utilize the method of functional magnetic resonance imaging (fMRI) in combination with self-report on perception of the stimuli as well as behavioral measures. FMRI also allows the examination of whether humans and robots elicit the same processes of what is called social cognition. Evaluating of and reasoning about other human beings falls under social cognition, because “Social cognition has as its objects humans and human affairs; it means cognition and knowledge about people and their doings.” (Flavell & Miller, 1998, p. 851). It is, however, unclear whether very human-like robots elicit social cognitive processes at all and if yes whether they elicit them to the same degree.

The following sections will summarize briefly the two types of explanations that will be central for this last study (perception-oriented and evolutionary-biological approaches) and empirical evidence for these explanations (section VI.1.1). Subsequently, section V.1.2 will introduce three research fields from the neurosciences which are relevant for the explanations under investigation: person perception and face recognition, social cognition and the social brain hypothesis, and disgust and the behavioral immune system. For these topics related empirical work with regard to human-human interaction and human-robot interaction will be reviewed. Finally, the research questions and hypotheses are presented in section V.1.3.

1.1 Explanations for the uncanny valley effect

As discussed in section II.3 proposed explanations can be classified as perception-oriented approaches, evolutionary-biological approaches, and cognitive-oriented approaches. Central to this study are the perception-oriented and evolutionary-biological approaches. In the following these proposed explanations and related empirical evidence will be shortly reviewed (also cf. section II.4.3 for an extended review).

1.1.1 Perception-oriented approaches

Quite a number of studies examined perception-oriented approaches such as *conflicting perceptual cues, the violation of previously triggered expectations, errors in the prediction of movement* or *uncertainty at category boundaries.* The underlying assumption for these explanations is a mismatch between expectations about perceptions and actual perceptions in whatever form, which causes some kind of additional processing on how to interpret, categorize, or react to this phenomenon. It has been assumed that this state of additional processing elicits some kind of uncertainty or cognitive dissonance which is subsequently negatively interpreted and thus the origin of the uncanny valley effect (e.g. MacDorman et al., 2009).

Studies in this area examined prediction errors caused by perceptual mismatches between aspects of appearance (c.f. section II.4.3.1, e.g. Burleigh et al., 2013; Cheetham et al., 2011; Cheetham et al., 2013; Green et al., 2008; MacDorman et al., 2009; Seyama & Nagayama, 2007; Seyama & Nagayama, 2009; Yamada et al., 2013), between appearance and movement (c.f. section II.4.3.1, e.g. Chaminade et al., 2005; Chaminade et al., 2010; Gazzola et al., 2007; Gobbini et al., 2011; Kilner et al., 2003; Kupferberg et al., 2012; Miura et al., 2008; Oberman et al., 2007; Oztop et al., 2004; Saygin & Stadler, 2012; Shimada, 2010; Tai et al., 2004; Wykowska et al., 2012), and between appearance and voice (c.f. section II.4.3.1, Mitchell et al., 2011).

With regard to ***mismatches in appearance and movement*** most studies used brain imaging techniques. It has been found that humans and robots both activate brain areas involved in action observation, face recognition and emotional processing, but the areas of activation, the amount of activation, and its laterality can depend on the quality of behavior (mechanic vs. biological movement), perceived intentionality of movement, and the type of robot displayed (robot arm, android, mechanical robot, robot face, bi-pedal robot, wheeled robot). Hence, the results are inconsistent. Furthermore, due to methodological constraints, practicability, and sheer restricted availability of robots these studies often compare movement of one human with movement of one specific type of robot and thus cannot address the variety of robot appearances. Their results are thus hardly generalizable. It is also difficult to relate these studies to the studies presented in this work, since they are based on different stimulus material – videos instead of pictures. There are, however, three studies comparing different human and robotic facial expressions which demonstrated that both humans and robots evoked activity in face-responsive regions (Chaminade et al., 2010; Dubal et al., 2011; Gobbini et al., 2011). Since face recognition also takes place when perceiving still images instead of moving ones, the examination of activation in face-sensitive brain areas during perception of a variety of human and robot stimuli could be a way to relate findings from previous fMRI studies based on video stimuli to the current study which will be based on pictures.

Mismatches in aspects of appearance have most often been examined using pictures of humans morphed with pictures of robots, dolls, or virtual faces or using solely virtual faces which have been varied with regard to different aspects of appearance. Thus properties in the faces under examination could be changed gradually (e.g., Burleigh et al., 2013; Cheetham et al., 2011; Cheetham et al., 2013; Green et al., 2008; MacDorman et al., 2009; Seyama & Nagayama, 2007; Seyama & Nagayama, 2009; Yamada et al., 2013). Results showed that morph sequences with facial proportions deviating from the norm elicited uncanny valley related responses. This was referred to as feature atypicality (cf. Burleigh et al., 2013; MacDorman et al., 2009; Seyama & Nagayama, 2007). However, the sensitivity for deviating facial proportions was influenced by the perceived human-likeness (MacDorman et al., 2009; Seyama & Nagayama, 2007) and attractiveness of faces (Green et al., 2008). Furthermore, morph sequences between human and virtual faces seem to produce uncertainty at the boundaries between the categories. Studies applying discrimination and identification tasks demonstrated category uncertainty at category boundaries as indicated by decreased accuracy, higher response latency, and increased decision uncertainty (Cheetham et al., 2011; Cheetham et al., 2013; Yamada et al., 2013). Findings of an fMRI study by Cheetham et al. (2013) also using discrimination and identification tasks revealed that physical change *within a category* caused activation in bilateral mid-fusiform areas and a different right mid-fusiform area which are involved in face recognition. Physical changes *between categories*, however, elicited activation depended on the direction for category change (human-to-avatar vs. avatar-to-human). Cheetham et al., thus, see the uncanny valley effect closely related to category processing since participants showed increasing reaction times and increased decision uncertainty for those morphs close to the boundary. Altogether, in examinations on mismatches in aspects of appearance only faces have been used and not full body images. Moreover, the faces in use were mostly very human-like (e.g. virtual human face morphed into real human face). Very mechanical robots (e.g. without facial features) have not been included so far.

Uncanny valley related responses, e.g. negative evaluations of robots, can also occur across modalities as was demonstrated by a study examining ***mismatches of appearance and voice*** (Mitchell et al., 2011).

1.1.2 Evolutionary-biological approaches.

As another possible explanation it has been proposed that uncanny valley responses might be due to an evolutionary developed mechanism to *avoid the risk of infection* and the risk of *genetically inadequate mating partners* (MacDorman & Ishiguro, 2006) which is disgust. “Disgust is an evolved psychological system for protecting organisms from infection through disease avoidant behaviour." (Curtis, Barra, & Aunger, 2011, p. 389). According to Schaller and Park (2011) this psychological system - also called the behavioral immune system - comprises mechanisms to detect cues connoting the presence of infectious pathogens in the immediate environment. Consequently, disease-relevant emotional and cognitive responses are triggered which in turn facilitate behavioral avoidance of pathogen infection (cf. Schaller & Park, 2011, p. 99). It has been argued that the high sensitivity of this system can be explained in terms of cost-benefit functions for automatic defenses to threats which are calibrated to minimize false-positive errors at the expense of increasing false-negative errors (Nesse, 2005). Therefore, the mechanism undermines the risk of falsely categorizing a threat as non-threatening by oversensitivity to these cues. In consequence, "the system responds to an overly general set of superficial cues, which can result in aversive responses to things (including people) that pose no actual threat of pathogen infection" (Schaller & Park, 2011, p. 99). Hence, for instance, people with physical disabilities (e.g., limb amputation due to accident; Park et al., 2003; or people suffering from obesity Park et al., 2007) might elicit a reaction of the behavioral immune system. Although, not only people, but also objects possess particular types of prepared features that connote disease (Oaten, Stevenson, & Case, 2009), it is expected that the likability for such a reaction increases with increased human-likeness, because then the object will be more likely classified as conspecific (Burleigh et al., 2013) and "if a feature on a conspecific stimulus is sufficiently atypical, then it can be expected to trigger one of these mechanisms independently of any real danger" (Burleigh et al., 2013, p. 760). MacDorman and Ishiguro (MacDorman & Ishiguro, 2006) stated that these mechanisms lead to increased *salience of one's own mortality* (cf. also section II.3.3).

Moreover, reactions of the behavioral immune systems have been examined in the context of mate selection (Tybur & Gangestad, 2011). Results suggest that human mate preferences are at least partly based on preferences for health. *Physical attractiveness* serves as an indicator for health, or in other words fitness and fertility, and is thus a crucial factor in mate selection. As stated previously, the "rules" of physical attractiveness are presumably also applied when judging android robots, and androids are presumably uncanny to the extent to which they differ from the nature norm of physical attractiveness (MacDorman & Ishiguro, 2006).

There are actually only three studies which examined evolutionary-biological explanations for uncanny valley related reactions. Ho et al. (2008) showed participants pictures of robots and asked them to evaluate the robots (in terms of how creepy, strange, eerie the robots are perceived to be) and to indicate how participants feel during when looking at the robot. They found that emotional statements about fear were connected with the attributes creepy, strange and eerie. They discuss that based on their results no direct conclusion can be drawn as to whether the uncanny valley is due to the fear of one's own mortality or due to mechanisms for pathogen avoidance. *Mortality salience* as a possible explanation for the uncanny valley has been experimentally tested by MacDorman (MacDorman, 2005b, also reported in MacDorman & Ishiguro, 2006). Participants who were presented with a picture of a turned-off female android instead of a healthy young woman, filled in more death related words in a subsequent word-completion task and exposed distal defense reactions according to the terror management theory (e.g., showing preferences for worldview supporting information). Lastly, Burleigh et al. (2013) examined how atypical features in virtual faces (e.g. enlarged eye size of one eye) influences perceptions with regard to likability and eeriness and found that greater feature atypicality, combined with less human-likeness, resulted in higher eeriness ratings. Altogether, these three studies demonstrated that experiencing of fear (indicated by self-report) is correlated with ratings of robots on eeriness and uncanniness (Ho et al., 2008), that atypical features in virtual faces contribute to eeriness ratings (Burleigh et al., 2013); and that a picture of a switched-off android elicits mortality salience measured by means of distal defense reactions (MacDorman, 2005b). It is, however, unclear whether participants experienced disgust or whether their behavior reflects avoidance behavior as it would be elicited by the behavioral immune system.

1.2 Related work in the Neurosciences

In this fourth study fMRI techniques will be utilized to experimentally test the proposed explanations for the uncanny valley effect. FMRI data provides information on processes which are not accessible via introspection. In combination with self-report or behavioral data, it allows to a certain extent to draw conclusions on how these processes influence participants self-reported perceptions and their behavior. Moreover, it can be examined whether humans and robots elicit the same perceptual and cognitive processes on the level of brain activity.

Building up on previous work on possible explanations for the uncanny valley effect, three research fields from the neurosciences were identified which are relevant for the explanations under investigation.

First, researchers found that robotic faces evoked activity in face-responsive brain regions (Chaminade et al., 2010; Dubal et al., 2011; Gobbini et al., 2011). Thus, empirical findings from the neurosciences with regard to person perception and face recognition are of interest.

Second, the results from the interviews (Study 1) demonstrated that participants started reasoning about the capabilities of the very human-like android Geminoid HI-1. The robot was perceived as the potentially most dangerous robot in the set of stimuli, because of its human form and connected with this the assumed cognitive abilities. Moreover, some participants reported to feel pity for CB2. Empathy is “a complex form of psychological inference in which observation, memory, knowledge, and reasoning are combined to yield insights into the thoughts and feelings of others” (Ickes, 1997, p. 2). These results lead to the assumption that more human-like robots induce social cognition processes in humans. Consequently, empirical findings from the neurosciences with regard to social cognition are relevant for this study and will be reviewed.

Third, the evolutionary-biological approaches are partly based on the assumption that negative responses towards very human-like robots are due to an overreaction of the behavioral immune system. In Study 1, when evaluating CB2 some participants unprompted reported to feel disgusted by the robot and in Ho et al. (2008) participants had to indicate whether robots made them feel disgusted or not. However, not all android robots elicited these reactions during the interviews (Study 1) and disgust was not the most significant predictor for participants’ evaluations of robots in Ho et al. either. Commonly, disgust is a very deep-routed and straight forward emotional reaction. It seems, however, not very prominent in the context of human-robot interaction. Different explanations for this are imaginable: a) emotional experiences based on disgust are not very strong when perceiving very human-like robots, b) the reactions are not interpreted correctly and mixed with other emotional experiences (e.g. fear), or c) participants simply do not experience disgust when perceiving robots. FMRI allows a direct examination of whether brain areas related to the experience of disgust are activated during the perception and evaluation of very human-like robots.

For these three topics related empirical work with regard to human-human interaction and human-robot interaction will be reviewed.

1.2.1 Person Perception and face recognition

Using videos it was shown that robotic faces elicit comparable activity in brain areas associated with face recognition just as human faces do (Chaminade et al., 2010; Dubal et al., 2011; Gobbini et al., 2011). Likewise, pictures of virtual and human faces activated the according brain areas (Cheetham et al., 2013). The responsive area is called the fusiform face area (FFA, cf. Kanwisher, McDermott, & Chun, 1997). The FFA is located in the fusiform gyrus or the immediately adjacent cortical areas. Kanwisher, McDermott and Chun (1997) report greater activation in the right than left fusiform gyrus for right handers and assume a lateralization of the FFA in the right hemisphere. Kanwisher et al. describe as additional area involved in face recognition a superior and lateral location in the right hemisphere in the region of the middle temporal gyrus (STS). In general, the FFA has been found to respond more to faces than to comparison stimuli, such as scrambled faces, (scrambled) houses or other (scrambled) objects (Courtney, Ungerleider, Keil, & Haxby, 1997; Kanwisher et al., 1997; Puce, Allison, Gore, & McCarthy, 1995; Puce, Allison, Asgari, Gore, & McCarthy, 1996; Sergent, Ohta, & MacDonald, 1992).

Based on the example of the FFA the possibility of perception modules, which are specialized on the perception of certain objects, has been discussed (Kanwisher et al., 1997; Pinker, 1997). Patient studies with people suffering from either a face perception disorder (McNeil & Warrington, 1993) or an object recognition disorder (Behrmann, Moscovitch, & Winocur, 1994) suggest that faces a) are processed differently (in terms of location in the brain) than objects and b) are processed configural or holistically based on their geometrical features which are summarized and compared to an average face template (Kanwisher et al., 1997; Pinker, 1997). Pinker argues that "if objects other than faces (animals, cars) have some of these geometric features, the module will have no choice but to analyze them, even if they are most useful for faces. To call a module a face-recognizer is not to say it can handle only faces, it is to say that it is optimized for the geometric features that distinguish faces because the organism was selected in its evolutionary history for an ability to recognize them" (Pinker, 1997, p. 274). Hence, the FFA might be reacting especially strong to robotic faces (in comparison to other objects) because their geometrical features often copy those of humans. Indeed a study using magnetoencephalography demonstrated "that objects incidentally perceived as faces evoked an early (165ms) activation in the ventral fusiform cortex, at a time and location similar to that evoked by faces, whereas common objects did not evoke such activation." (Hadjikhani et al., 2009, p. 403). Figure 42 shows examples of face-like stimuli used in this study which certainly remind of geometrical patterns in robotic faces.

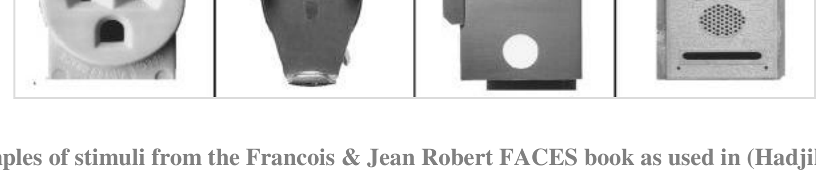


Figure 42: Examples of stimuli from the Francois & Jean Robert FACES book as used in (Hadjikhani et al., 2009)

Chaminade et al. (2010) also discussed that the increased activation in the FFA for robotic faces in comparison to human faces found in their study might be due to additional processing needed in the face module to decide on whether the stimuli is a human face or not. They draw on similar findings from visual word recognition were increased responses were observable in the visual word form area when the visual appearance of a written word is degraded (Cohen, Dehaene, Vinckier, Jobert, & Montavont, 2008). Dubal et al. (2011) come to similar conclusions.

1.2.2 Social cognition

All cognitions which are influenced by individuals of the same species (conspecifics) are subsumed under the term social cognition. This includes the encoding, storage, retrieval, and processing of information about conspecifics. Hence, "social cognitive neuroscience is concerned with the representation of the self, the perception of social groups (such as race and gender stereotypes), and the ability to make inferences about the knowledge, beliefs and desires of the self and of others (known as theory of mind (ToM))." (Amodio & Frith, 2006, p. 286). As mentioned previously, participants' statements in the interviews (Study 1) suggest that participants thought about the cognitive (but also physical) capabilities of very human-like android robots. In addition, they reported to feel pity for CB2. These results lead to the assumption that more human-like robots induce social cognition processes in humans. This phenomenon has already been described in the field of media psychology and is known as the Ethopoeia concept: people automatically and unconsciously react to computers in the same way as they do towards other humans (c.f. Nass et al., 1997; Nass & Moon, 2000). Nass and Reeves' (Reeves & Nass, 1996) evolutionary approach to explain this phenomenon states that the human brain developed at a time when only human beings were able to show social behavior. To deal successfully with daily life, the human brain developed automatic responses, which are still in use today. Thus, "when our brains automatically respond socially and naturally because of the characteristics of media or the situations in which they are used, there is often little to remind us that the experience is unreal. Absent a significant warning that we've been fooled, our old brains hold sway and we accept media as real people and places" (Reeves & Nass, 1996, p. 12). These automatic or mindless (Langer, 1989; Langer, 1992; Langer & Moldoveanu, 2000; Nass & Moon, 2000) responses to contextual social cues trigger scripts and expectations, making active information processing impossible. Moreover, people have the tendency to use cognitive shortcuts and heuristics (Tversky & Kahnemann, 1974), and therefore apply rules from human-human interaction to human-computer interaction due to the perceived functional similarity (or provided social cues) between humans and computers such as the use of natural language (Turkle, 1984), interactivity (Rafaeli, 1990), and the filling of social roles traditionally filled by humans (Nass, Lombard, Henriksen, & Steuer, 1995; Mead, 1934). Studies in the field of human-agent interaction and human-robot interaction suggests that these effects can be amplified by the human-like appearance of technical artifacts. Recent work from the field of neurosciences supports the Ethopoeia concept by demonstrating that virtual agents and robots elicit brain activity comparable to those elicited by humans with regard to motor resonance (e.g. Chaminade et al., 2005; Chaminade et al., 2010; Gazzola et al., 2007; Gobbini et al., 2011; Miura et al., 2008; Kupferberg et al., 2012; Saygin et al., 2012; Shimada, 2010 ; Wykowska et al., 2012), face-recognition (Chaminade et al., 2010; Dubal et al., 2011; Gobbini et al., 2011) and emotional processing (Chaminade et al., 2010; Dubal et al., 2011; Gobbini et al., 2011; Miura et al., 2008, cf. Section 1.4.3.1). Moreover, there is empirical evidence that people (automatically) think about cognitive capabilities of robots: an fMRI study in which participants played a prisoner's dilemma game either against a computer partner, a functional robot, an anthropomorphic robot and a human partner revealed a linear increase brain activity in areas associated with ToM in correspondence with the increase of human-likeness of the interaction partner (computer < functional robot < anthropomorphic robot < human; Hegel et al., 2008; Krach et al., 2008). Participants' enjoyment of the interaction, the experience of competition as well as the perceived intelligence of the partner also increased with increased human-likeness. Although humans have no evidence that computers (agents, robots) "can reflect on their states of 'mind'" (Dunbar, 1998, p. 188), it seems that people unconsciously initiate reasoning about the others' (the robots') capabilities, mental states, and beliefs.

According to the "social brain hypothesis" (Dunbar, 1998), it is rather unlikely that social cognition is an aggregation of simple, nonsocial processes which account for complex social behavior. In contrast, it has been assumed that some brain areas have a uniquely social function (Adolphs, 1999; Amodio & Frith, 2006; Saxe, 2006). Social cognition processes are associated with a network of brain regions including (amongst others) the medial frontal cortex (MFC), the anterior cingulate cortex (ACC), the temporoparietal junction (TPJ), the superior temporal sulcus (STS) and the temporal poles (Amodio & Frith, 2006). The MFC especially has been suggested as having a special role in social cognition. The other regions, however, are involved also in more general functions. A meta-analysis of medial frontal cortex (MFC) activations by Amodio and Frith suggests "that social cognition tasks, which involve self-knowledge, person perception and mentalizing, activate areas in the *anterior rostral MFC* (arMFC). By contrast, activations from action-monitoring tasks occur in the *posterior rostral region of the MFC* (prMFC), and activations from tasks involving the monitoring of outcomes occur in the *orbital MFC* (oMFC).” (Amodio & Frith, 2006, ‘at a glance’). Hence, the prMFC will not be central to this study, because the stimulus material will contain pictures instead of videos and thus no action observation processes will take place.

Social cognitive tasks which involve reflection on mental states of the self or the mental states of others will elicit activity in the arMFC. With regard to ToM, fMRI studies based on ToM games played against computers frequently showed activation in the dorsomedial prefrontal region in the vicinity of the paracingulate sulcus, in the posterior superior temporal sulcus (STS) and in the temporoparietal junction (TPJ; cf. Amodio & Frith, 2006; Behrens, Hunt, & Rushworth, 2009; Saxe, 2006). Moreover, the amygdala (c.f. Amodio & Frith, 2006) and the precuneus (cf. Rilling, Sanfey, Aronson, Nystrom, & Cohen, 2004; Krach et al., 2008) have been implicated in mental state attribution processes.

The ventral region (orbital MFC) is involved in monitoring reward and punishment, and in the updating of the predicted value of outcomes. However, tasks on reward and reinforcement not only involve the oMFC, but also the amygdala, ventral striatum and anterior cingulate cortex sulcus (ACCs, cf. Behrens, et al., 2009; Grabenhorst, Schulte, Maderwald, & Brand, 2013). Behrens summarizes that “these structures might underlie the value associated with a particular person, just as they underlie values assigned to nonsocial stimuli.” (Behrens, et al., 2009, p. 1160; cf. Rolls, 1999). In line with this assumption it has been found that activity in the ventral striatum that increases in receipt of monetary rewards also increases when subjects receive positive appraisals by their peers (e.g. Izuma, Saito, & Sadato, 2008; Izuma, Saito, & Sadato, 2010a; Izuma, Saito, & Sadato, 2010b; Saxe & Haushofer, 2008). Thus, regions associated with monitoring awards might also be relevant for rewards that can be expected from different persons.

1.2.3 Disgust

Disgust has been characterized as an evolved mechanism for protection from infection (Curtis et al., 2011, p. 389). There exist subtypes of disgust (distaste, physical disgust, moral disgust) which are assumed to serve different purposes (avoid toxins, avoid infections, avoid compromising reproductive fitness, avoid unsustainable interaction partner) with the goal to protect the individual from physical harm or the risk of inappropriate mating and loss of reproductive fitness (Chapman & Anderson, 2012). Accordingly, disgust can be elicited by a diverse set of stimulus triggers such as unpleasant tastes and smells, the sight of vomit or feces, blood, bodily deformities, contact with unfamiliar individuals, and violation of social and moral norms. Neuroanatomically, the insula processes a person's sense of disgust with regard to tastes, smells and visual disgusting stimuli (cf. Calder et al., 2007; Jabbi, Bastiaansen, Keysers, & Lauwereyns, 2008; Koenigs, 2013; Wicker et al., 2003; Wright, He, Shapira, Goodman, & Liu, 2004) as well as imaginations of disgusting stimuli (Fitzgerald et al., 2004; Jabbi et al., 2008). It seems that besides the insula also other brain areas are involved in perceiving and processing disgust stimuli such as the amygdala and others (Schaich Borg, Lieberman, & Kiehl, 2008). Moreover, different types of disgust stimuli (e.g. pathogen, incest, violation of moral norms) recruit different, but still overlapping, brain networks (Schaich Borg et al., 2008; Moll et al., 2002). However, not all possible stimuli have been investigated so far. Although there is empirical evidence for anxiety reactions and behavioral avoidance of people with different physical disabilities (Comer & Piliavin, 1972; Blascovich, Mendes, Hunter, Lickel, & Kowai-Bell, 2001, Hebl, Tickle, & Heatherton, 2003, c2000), there has been no investigation on whether this kind of stimuli induces comparable activity in disgust relevant brain structures.

1.3 Research questions and hypotheses

The testing of the introduced and discussed explanatory approaches for the uncanny valley will be central to this study. More specifically, it will be examined whether uncanny valley related reactions are observable in participants' evaluations of humans and robots with regard to uncanny valley related rating dimensions (likability, familiarity, human-likeness) and regarding behavioral measures (decision making). Subsequently, it will be analyzed whether these behavioral effects, if detectable, can be explained by the proposed explanations. For this purpose, relations between behavioral measures and activity in relevant brain areas will be analyzed.

Cheetham et al. (2011) discuss that Mori's theory did not consider that there might be variation in human-like appearance also within the human category not only when regarding non-human objects. Although the images used in this study were morphed and thus artificial, some of these technically artificial morphs were explicitly judged to be human. This tackles a methodological uncanny valley critique: in a lot of studies "the human image is treated as a general point of reference irrespective the fact, as shown in the present study, that there are differences in human-likeness within the human category" (p. 9). Therefore, in contrast to previous work and the stimulus material used in Study 3, the set of stimulus material will not only include different groups of robots (mechanoid, humanoid, android), but also different groups of humans (healthy humans, disabled humans, “artificial” humans) in order to reflect the far right end of the graph depicted by Mori (cf. Figure 5) and address the fact that also human stimuli can vary in human-likeness.

General evaluation of humans and robots and neural correlates of these evaluations

Participants will rate the stimuli with regard to perceived likability, familiarity and human-likeness. It can be assumed that the human stimuli will be rated as more human-like than the robotic stimuli. Healthy humans in particular can be expected to receive highest ratings on human-likeness. Thus, it is hypothesized that:

H1a) Human stimuli will be rated as more human-like than robotic stimuli, and

H1b) Healthy humans will be evaluated as more human-like than disabled or artificial humans, and android, humanoid or mechanoid robots.

Based on the results of Study 3, it is assumed that perceived human-likeness influences participants’ perceptions of the likability and familiarity of the stimuli. Accordingly, it is hypothesized that:

H2: The robots’ perceived human-likeness predicts evaluations of the robots with regard to familiarity and likability.

Furthermore, it will be examined whether brain areas can be identified which are involved in the evaluation of likability, familiarity, and human-likeness of humans and robots. Thus, it is asked:

RQ1: Are trial-wise ratings on likability, familiarity and human-likeness correlated with brain activity?

RQ2: Are trial-wise rating differences (with regard to likability, familiarity and human-likeness) between two stimuli (in the decision trials) correlated with brain activity during rating trials?

Decisions between humans and robots and neural correlates of these decisions

During the decision task, participants will decide between two stimuli from different categories with regard to a personally relevant question (from whom they would like to receive a gift). Planned contrasts for these decision trials are comparisons between healthy humans and the five other categories (disabled humans, artificial human, android robots, humanoid robots and mechanoid robots) and android robots and the four remaining categories (disabled humans, artificial humans, humanoid robots and mechanoid robots). Decision uncertainty will probably not arise in all planned decision contrasts. It can be assumed that participants' generally will decide in favor for the healthy human stimulus and that this decision is rather easy. However, the decision might be harder if participants have to decide between android robots and other categories. The related hypotheses are:

H3a: For decisions involving healthy humans, participants will chose in favor for the healthy human.

H3b: For decisions involving healthy humans, participants will report less decision uncertainty compared to decisions involving android robots.

In previous studies, the uncanny valley effect was often examined using either self-report or behavioral measures. The present paradigm allows examining whether differently assessed uncanny valley reactions are related. Thus, it is hypothesized that:

H4a: Trial-wise rating differences with regard to likability between two stimuli predict participants' choice.

H4b: Trial-wise rating differences with regard to familiarity between two stimuli predict participants' choice.

H4c: Trial-wise rating differences with regard to human-likeness between two stimuli predict participants' choice.

Furthermore, it can be assumed that during the two tasks (rating and decision-making) different brain areas will be activated. It is, however, unclear which areas will be activated. Thus, it is asked:

RQ3: Are different brain areas activated during the two tasks - rating and decision-making - and which are these brain areas?

Moreover, previous work showed that decision uncertainty elicits increased brain activity in medial frontal brain areas (Grindband et al., 2006; Critchley, Mathias, & Dolan, 2001; Ridderinkhof, 2004). Therefore, it is asked:

RQ4: Are trial-wise confidence ratings (positively or negatively) correlated with brain activity in medial frontal areas at the time of choice?

In addition, the aim is to identify brain areas which are involved in making choices based on perceived likability, familiarity, and human-likeness of robots and humans. Thus, it is asked:

RQ5: Are trial-wise rating differences (with regard to likability, familiarity and human-likeness) between two stimuli (in the decision trials) correlated with brain activity during decision trials?

Reproducing the uncanny valley

Similarly to Study 3, the obtained rating data will be analyzed following Burleigh et al.'s approach to explore which mathematical function best predicts the obtained data in order to draw conclusions on the meaningfulness of the uncanny valley graph. Accordingly, it is asked:

RQ6: Which mathematical function (linear, quadratic, cubic) fits best to the obtained data?

Testing perception-oriented explanations: person perception and social cognition

Dubal et al. (2011), Chaminade et al. (2010), Gobbini et al. (2011), and Cheetham et al. (2011) consistently showed that robotic or virtual faces elicited processes of face recognition in the fusiform gyrus similar to those elicited by human stimuli. Altogether, this work suggests that robotic faces trigger the common template or module for faces due to the geometrical characteristics (cf. Kanwisher et al., 1997; Pinker, 1997). However, it seems that additional processing is needed to code a robot face as a face. Accordingly, it is hypothesized that the perception of very human-like robots cause increased brain activity in the fusiform face area during rating trials. More specifically, we assume that:

H5a: There will be no differences in brain activity in the fusiform gyrus between healthy humans and artificial humans, and no differences between healthy humans and disabled humans (healthy humans = artificial humans; healthy humans = disabled humans).

H5b: There will be increased brain activity in the fusiform gyrus when comparing robots with healthy humans (android robot > healthy humans; humanoid robots > healthy humans; mechanoid robots > healthy humans).

H5c: There will be increased brain activity in the fusiform gyrus when comparing android robots with disabled or artificial humans (android robots > disabled humans; android robots > artificial humans).

With regard to social cognition processes, Krach et al. (2008) showed that increased anthropomorphism caused increased brain activity in areas relevant for ToM (e.g. TPJ). The results of Study 3 demonstrated that the stimulus material varies significantly with regard to perceived human-likeness. Thus, it can be assumed that there will be differences between the six stimulus categories with regard to social cognition processes. Accordingly, it is hypothesized that:

H6: There will be increased brain activation in areas associated with ToM when comparing the human stimuli with the robotic stimuli.

Testing evolutionary-biological explanations: disgust

MacDorman and Ishiguro (2006) discussed that uncanny valley related responses are based on disgust as evolutionary developed mechanism to *avoid the risk of infection* and the risk of *genetically inadequate mating partners*. According to Schaller and Park (2011) this psychological system frequently causes an oversensitivity bias. The system is calibrated to reduce false-negative errors and thus reacts towards diverse superficial stimuli resulting in the tendency to 'overperceive' people in the environment displaying heuristic disease cues. In consequence, also people with physical disabilities (e.g., limb amputation due to accident; Park et al., 2003; or people suffering from obesity Park et al., 2007) might elicit a reaction of the behavioral immune system. It has been proposed that very human-like robots might also provide heuristic disease cues and thus elicit responses from the behavioral immune system. Thus, it is hypothesized:

H7: In comparison to healthy humans, disabled humans, artificial humans and android robots will elicit increased neural activity in the insula and amygdala (disabled humans > healthy humans; artificial humans > healthy humans; android robots> healthy humans).

2. Method

2.1 Experimental design

The experiment comprised six experimental conditions defined by six categories of stimuli: healthy humans, disabled humans, artificial humans, android robots, humanoid robots and mechanoid robots (explained in more detail in section VI.2.2). Participants underwent two sessions with functional localizers and six experimental sessions of fMRI scanning in the following order: session 1, session 2, functional localizer fusiform-face area, session 3, session 4, functional localizer disgust, session 5, session 6. In each experimental session participants were asked to perform rating and choice tasks (explained in sections VI.2.2 and VI.2.3). In total, participants performed 72 trials of the rating task and 108 trials of the choice task. The stimulus material and the two tasks will be described in more detail in the following.

2.2 Stimulus material & pre-test

For the experimental design six categories of stimuli (healthy humans, disabled humans, artificial humans, android robots, humanoid robots, mechanoid robots) with six pictures each were needed. For this purpose a variety of stimulus material was generated and evaluated in a pre-test.

Pictures of healthy humans were searched for in picture databases (www.shutterstock.com; www.gettyimages.com, www.istockphoto.com, www.fotolia.de). Only pictures showing people in a standing, frontal position without exaggerated postures or exaggerated facial expressions in front of a white background were considered for the pretest. Pictures with extreme colors (e.g. bright red) were excluded. In total, thirteen healthy humans (6 female, 7 male) were evaluated.

Pictures of disabled humans were also searched for in picture databases (www.shutterstock.com; www.gettyimages.com, www.istockphoto.com, www.fotolia.de). Only pictures showing people with congenital disabilities (e.g. Down syndrome, spasticity, congenital amputation) were considered for the pretest. Since pictures of disabled humans available are rather rare the pictures are less standardized than the healthy humans. If possible, pictures were chosen showing the people in a standing or sitting frontal position with a white background. In total, nine disabled humans (3 female, 6 male) were evaluated.

Pictures of artificial humans were created based on portraits of people who received plastic surgery photographed by Phillip Toledano (Toledano & Hunt, 2011). The pictures present the people in dramatic light and reduced coloring. According to the orientation of the heads depicted in the Toledano portraits, pictures were taken of volunteers exposing the same head and body orientation, under similar light conditions. The pictures of the bodies were also reduced in coloring and matched to the portraits, resulting in full body images of humans who share some irritating features: reduced coloring which gives them a greyish color, mismatches in the proportion of head and body, exaggerated facial features (due to plastic surgery). In total, nine artificial humans (4 female, 5 male) were evaluated.

For the category of the android robots, the pre-test included the four android robots from Study 3 and four more actual available android robots. Again, pictures showed the robots in a standing or sitting frontal position without exaggerated postures or exaggerated facial expressions. In total, ten android robots were evaluated.

For the humanoid and mechanoid robots pictures of the clusters identified in Study 3a were used. Since cluster five of the cluster analysis in Study 3a featured only humanoid robots, these were used for this category in the pre-test. For the category mechanoid robots, the cluster six of the cluster analysis in Study 3a were used, because those robots were among the most unfamiliar and strange as well as most mechanical robots. In total, eight mechanoid robots were evaluated.

The humans and robots were evaluated with regard to eight items (likable, unpleasant, familiar, uncanny, intelligent, disgusting, human-like, and attractive) rated on 6-point Likert scale ranging from “I fully agree” to “I do not agree at all”. To keep the test short, two sets of pictures were created which were evaluated by in total 77 participants (39 participants completed set one, and 38 completed set two).

Mean values for each of the eight items and each of the stimulus pictures were calculated.

With regard to the healthy humans, those pictures of female and male healthy humans were selected that provided the best fit of high likability, human-likeness, and attractiveness and low ratings in uncanny, unpleasant and disgusting (cf. Table 37 & 38 for results; cf. Figure 43 for the final stimuli).

Table 37: Pre-test results for healthy humans (HH; women)

	included stimuli			**excluded stimuli**		
	HH3	**HH4**	**HH5**	**HH excl. 1**	**HH excl. 2**	**HH excl. 3**
likable	4.62	4.50	3.55	3.91	4.68	3.43
unpleasant	1.69	1.81	2.50	2.22	1.74	2.43
familiar	4.12	3.90	3.30	3.52	4.26	3.30
uncanny	1.35	1.55	1.60	1.78	1.47	1.87
intelligent	4.23	4.02	3.90	3.96	4.05	4.17
disgusting	1.42	1.57	1.80	1.61	1.89	1.78
human-like	5.04	5.19	5.15	4.78	5.37	4.57
attractive	4.31	4.48	4.35	5.00	3.53	4.09

Table 38: Pre-test results for healthy humans (HH; men)

	included stimuli			excluded stimuli			
	HH1	HH2	HH3	HH excl. 4	HH excl. 5	HH excl. 6	HH excl. 7
likable	4.80	4.81	4.55	4.05	3.30	3.84	4.12
unpleasant	1.75	1.81	1.95	2.35	2.65	2.05	2.35
familiar	4.05	4.29	4.30	3.95	3.35	3.42	3.69
uncanny	1.45	1.43	1.60	1.60	2.09	1.79	1.65
intelligent	4.30	4.29	3.90	4.40	3.87	3.84	3.96
disgusting	1.50	1.67	1.65	1.90	2.30	1.58	1.81
human-like	5.25	5.19	5.25	5.05	4.57	5.11	4.54
attractive	4.70	4.33	3.65	3.85	3.04	3.68	3.73

With regard to the pictures of disabled humans it was found that six pictures were rated rather similarly with regard to all eight items. However, three pictures were rated more positively which could be due to the fact that the people on all three pictures showed a rather bright smile. Thus, these three pictures were excluded and the remaining six pictures were kept for the main study. The remaining pictures were rated as rather likable and rather highly human-like, but received medium ratings for intelligent, familiar and unpleasant, and low ratings for attractiveness (cf. Table 39 for results; cf. Figure 44 for the final stimuli). These pictures were rated as slightly more disgusting than the healthy humans, but this rating was still rather low.

Table 39: Pre-test results for disabled humans (HD)

	included stimuli						excluded stimuli		
	HD1	HD2	HD3	HD4	HD5	HD6	HD excl. 1	HD excl. 2	HD excl. 3
likable	3.82	3.41	3.60	4.11	3.63	4.00	4.40	4.45	4.62
unpleasant	2.70	3.14	3.20	2.79	3.00	2.95	2.15	2.59	2.62
familiar	3.12	2.86	3.15	3.11	3.11	2.80	3.45	3.00	3.00
uncanny	2.55	2.50	2.60	2.21	2.21	2.75	1.75	2.31	1.90
intelligent	3.73	3.23	3.30	4.37	2.84	3.60	4.15	3.38	4.14
disgusting	2.42	2.77	2.70	2.16	2.37	2.60	1.85	2.17	2.19
human-like	4.67	4.73	4.90	5.11	4.79	4.85	5.25	4.72	5.24
attractive	3.12	2.23	2.35	2.37	2.11	2.40	3.25	2.59	2.24

The artificial humans shared low ratings in likability, familiarity, and attractiveness; medium ratings in intelligence, human-likeness, and disgusting; and rather high ratings in unpleasant and uncanny. The three pictures with the lowest ratings on unpleasantness and uncanniness were excluded. The remaining six pictures were used in the main study (cf. Table 40 for results; cf. Figure 45 for final stimuli).

Table 40: Pre-test results for artificial humans (HA)

	included stimuli						excluded stimuli		
	HA1	**HA2**	**HA3**	**HA4**	**HA5**	**HA6**	**HA excl. 1**	**HA excl. 2**	**HA excl. 3**
likable	2.50	2.35	2.80	2.35	2.40	2.32	3.43	2.75	2.95
unpleasant	3.90	3.81	4.05	3.80	4.00	4.00	2.57	3.70	2.95
familiar	2.60	2.35	2.65	2.55	2.45	2.21	2.67	2.60	2.53
uncanny	4.00	4.00	3.80	3.40	4.05	4.11	2.57	3.80	3.11
intelligent	3.55	2.96	3.60	3.40	3.40	3.42	3.27	3.85	3.74
disgusting	3.40	3.65	3.55	3.10	3.45	3.47	2.53	3.05	2.63
human-like	3.40	3.12	3.40	3.30	3.30	3.42	3.63	3.60	3.84
attractive	2.15	2.00	2.55	2.05	2.20	2.21	3.57	2.30	2.84

Regarding the category of the android robots, one android (Geminoid F) received very different ratings than any other robot in this group and thus was omitted. The other robots were evaluated quite similarly. However, one android (Hubo) was quite different than the other robots, since its head resembles that of Albert Einstein and thus might elicit other associations in the participants. Therefore, this robot was excluded and the remaining six robots were used in the main study (cf. Table 41 for results; cf. Figure 46 for final stimuli).

Table 41: Pre-test results for android robots (RA)

	included stimuli						excluded stimuli	
	RA1	**RA2**	**RA3**	**RA4**	**RA5**	**RA6**	**RA excl. 1**	**RA excl. 2**
likable	3.05	3.05	2.76	2.43	2.64	2.35	4.21	2.50
unpleasant	3.65	3.18	4.24	4.54	3.09	3.55	2.00	3.90
familiar	2.80	2.91	2.36	1.86	2.41	2.30	3.63	2.40
uncanny	3.70	3.59	3.80	4.00	3.86	3.80	2.11	4.25
intelligent	3.05	2.95	3.15	3.78	3.64	2.95	4.37	3.10
disgusting	3.05	3.09	3.58	3.78	2.82	3.20	1.63	3.85
human-like	2.75	3.00	3.30	2.86	2.73	2.60	5.00	2.05
attractive	3.15	2.77	2.24	1.51	2.55	1.85	4.79	1.65

The humanoid robots were rated rather similarly on all dimensions. Thus, the robots were excluded based on their design. Kobian as the only robot with facial features was excluded, as well as PR2 the only not mobile robot. The robots HRP2 and HRP3 are very similar, thus only one of these two was kept for the main study and lastly REEM was excluded from the sample. The remaining six robots were kept for the main study (cf. Table 42 for results; cf. Figure 47).

Table 42: Pre-test results for humanoid robots (RH)

	included stimuli						excluded stimuli			
	RH1	**RH2**	**RH3**	**RH4**	**RH5**	**RH6**	**RH excl. 1**	**RH excl. 2**	**RH excl. 3**	**RH excl. 4**
likable	2.35	2.24	2.69	2.21	2.65	2.86	2.80	1.95	2.37	2.75
unpleasant	3.30	3.12	3.00	3.07	3.12	2.45	3.45	2.95	2.79	3.00
familiar	2.50	2.16	2.88	2.41	2.54	2.32	2.45	2.05	2.37	2.90
uncanny	3.20	3.00	3.38	3.28	3.00	2.55	3.45	3.10	2.95	3.10
intelligent	2.75	2.72	3.54	2.69	2.27	3.23	2.80	3.45	3.42	2.85
disgusting	2.95	2.80	2.58	3.14	2.58	2.18	3.30	2.80	2.68	2.65
human-like	1.65	1.60	1.65	1.10	1.46	1.50	1.85	1.50	1.79	1.70
attractive	1.75	1.60	2.27	1.69	1.69	1.91	1.95	1.55	2.05	1.90

Regarding the mechanoid robots again the robots were rated very similarly. Thus, Armar and Popo were excluded from the sample, because of their rather distinctive colors (red and green). The remaining six robots were kept for the main study (cf. Table 43 for results; cf. Figure 48).

Table 43: Pre-test results for mechanoid robots (RM)

	included stimuli						excluded stimuli	
	RM1	**RM2**	**RM3**	**RM4**	**RM5**	**RM6**	**RM excl. 1 Armar**	**RM excl. 2 Popo**
likable	2.65	2.95	2.45	2.68	2.80	2.85	2.53	2.40
unpleasant	3.30	2.30	3.25	2.63	2.90	3.00	2.89	3.45
familiar	2.25	2.50	1.80	2.74	2.50	2.50	2.63	2.20
uncanny	3.15	2.45	3.35	2.63	2.70	3.10	2.79	3.35
intelligent	2.55	3.25	2.35	3.68	2.60	3.55	3.68	2.45
disgusting	2.90	2.45	2.95	2.37	2.65	2.65	2.21	3.30
human-like	1.50	1.45	1.50	1.63	1.60	1.85	1.79	1.60
attractive	1.65	2.50	1.95	1.74	1.85	1.95	1.89	1.70

Figure 43: Stimulus material in category "healthy human": HH1, HH2, HH3, HH4, HH5, HH6

Figure 44: Stimulus material in category "disabled human": HD1, HD2, HD3, HD4, HD5, HD6

Figure 45: Stimulus material for the category "artificial human": HA1, HA2, HA3, HA4, HA5, HA6

Figure 46: Stimulus material for the category "android robot": RA1, RA2, RA3, RA4, RA5, RA6

Figure 47: Stimulus material for the category "humanoid robot": RH1, RH2, RH3, RH4, RH5, RH6

Figure 48: Stimulus material for the category "mechanoid robot": RM1, RM2, RM3, RM4, RM5, RM6

The resulting stimulus material consists of six pictures for each of the six categories (cf. Figures 40-45). When necessary and if possible gender of the stimuli was balanced. However, due to the restricted original material it was not possible to balance for gender within the category of disabled and artificial humans. Both groups contain more pictures with male than with female people:

Categories of pictures and number of stimuli

1. Humans
    a. healthy humans (3 female, 3 male)
    b. disabled humans (1 female, 5 male)
    c. artificial humans (2 female, 4 male)
2. Robots
    a. android robots (3 female, 3 male)
    b. humanoid robots (6 pictures)
    c. mechanoid robots (6 pictures)

Visual stimulus presentation was controlled using the software PRESENTATION (Neurobehavioral Systems Inc., Albany, CA).

2.3 Rating task

The rating trials started with the presentation of a stimulus for 4 s, followed by a blank screen for 3 s. Afterwards, participants rated the stimulus with regard to its likability, familiarity and human-likeness on three separate visual analog scales, each presented for three seconds. The scales ranged from 1 (not at all likable / familiar / human-like) to 5 (very likable / familiar / human-like). The rating scales were followed by a variable inter-trial interval (ITI) with jittered duration of 2-6 s. An instruction was presented during the ITI (“rate” or “decide”) to inform participants about whether the next trial would be a rating or choice trial. Figure 49 shows schematically the time intervals of the stimuli presentation for one trial.

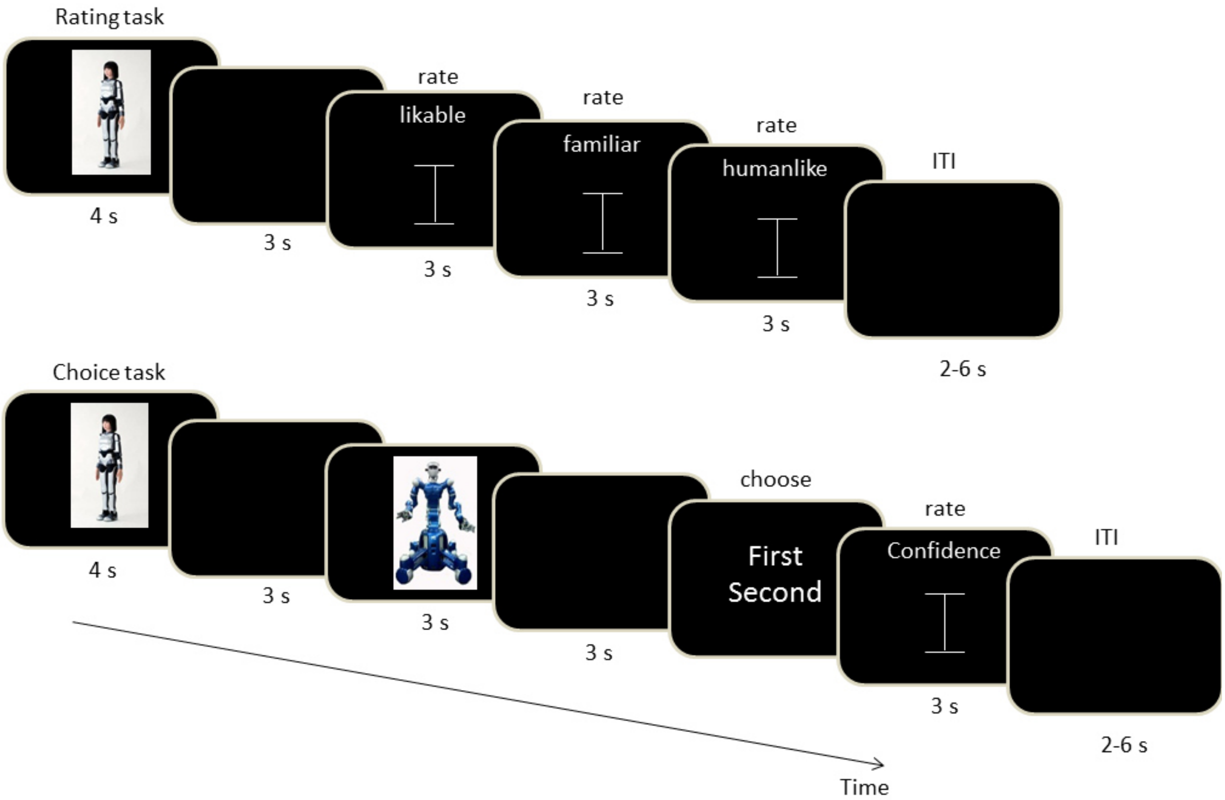


Figure 49: Experimental tasks

2.4 Choice task

The choice trials started with the presentation of the first stimulus for 4 s, followed by a blank screen of 3seconds. Then the second stimulus was shown, followed by a blank screen of 4s. Subjects were then prompted to report their choice by showing the options "first" and "second" on the monitor. Subsequently, participants rated their confidence level with regard to the previously reported decision on a separate visual analog scale presented for three seconds. The scale ranged from 1 (not at all confident) to 5 (very confident). Figure 49 shows schematically the time intervals of the stimuli presentation for one trial.

Subjects were instructed that they have to choose between two pictures with regard to the following scenario:

Prior to this study we asked all humans and robots to choose one item among four items which will be given to the volunteers as gratification for participation in this study. The four items were a movie theatre voucher, a package of dishwasher tabs, a bottle of sparkling wine, and a package of quality toilet bowl deodorizer blocks. Every person and robot made a *choice. You will see pictures of all these persons and robots, but will not receive information on who decided in favor for what item. During the choice task trial you will see two pictures each showing a person or a robot (in the possible combinations person-person, robot-person, and robot-robot). You shall decide in favor of the picture showing the robot or the person from whom you prefer to receive the previously chosen present. Since the time for decision making and reporting your decision is very short, please make a "gut decision". There will be easy and hard decisions. Thus, please indicate your level of confidence in the decision on a subsequent rating scale from 1 (not at all confident) to 5 (very confident).*

In total, nine contrasts between the six categories of stimuli were implemented. The healthy human category was compared with all other categories and the android category was compared with all other categories, resulting in the following nine contrasts:

1. healthy human vs. disabled human
2. healthy human vs. artificial human
3. healthy human vs. android
4. healthy human vs. humanoid
5. healthy human vs. mechanoid
6. android vs. disabled human
7. android vs. artificial human
8. android vs. humanoid
9. android vs. mechanoid

There were twelve choices per contrast. For these choices the six pictures from each category were tested against each other. Each comparison of a pair of pictures occurred only once. Six comparisons started with a picture of one category and six started with pictures of the other category. This resulted in a total of 108 choice trials (twelve in each of the nine contrasts).

2.5 Functional localizers

Functional localizers were used to determine the fusiform face area and brain areas associated with disgust such as the insula. While some anatomical structures can be very distinct other brain regions such as the primary visual cortex vary across individuals (cf. Saxe, Brett, & Kanwisher, 2006). Thus, functional localizers can serve as mechanism to identify the specific brain region which can be used in subsequent analysis. Technical problems occurred during scanning of the two functional localizers in this experiment resulting in incomplete logfiles with missing time stamps. Thus the localizers could not be used to reliably identify the brain areas in demand. For the sake of completeness, they will be described in the following.

2.5.1 Fusiform face area

Because participants' tasks in the experimental runs were to evaluate pictures and decide between two stimuli, a passive-viewing task for the functional localizer was chosen based on the recommendation that the localizer and the experimental task should be different (Berman et al., 2010). There were ten face stimuli and ten object stimuli, and each face or object was shown once. All faces had neutral expressions. Each stimulus was displayed for 2000 ms, with a 2000 ms fixation cross separating each stimulus. Participants were instructed to look at the faces and objects (cf. Figure 50 & 51), and at the end of the run indicate whether they had seen a specific object (a bike) which had been shown during the run. Visual stimulus presentation was controlled using the software PRESENTATION (Neurobehavioral Systems Inc., Albany, CA).

Figure 50: Examples for face stimuli used in the functional localizer for face recognition

Figure 51: Examples for object stimuli used in the functional localizer for face recognition and disgust

2.5.2 Disgust

Similarly to the face localizer, the disgust localizer comprised ten disgust stimuli and ten object stimuli, and each disgust or object stimulus was shown once. Each stimulus was displayed for 2000 ms, with a 2000 ms fixation cross separating each stimulus. Participants were instructed to look at the disgusting pictures and objects (cf. Figure 50 & 52), and at the end of the run indicate whether they had seen a specific object (a sofa) which had been shown during the run. The disgust stimuli were pictures showing physical disgusting situations including extremely dirty toilets with feces or vomit, and persons vomiting. Pictures were drawn from the International Affective Picture System (IAPS; Lang et al., 2008). Visual stimulus presentation was controlled using the software PRESENTATION (Neurobehavioral Systems Inc., Albany, CA).

Figure 52: Examples for disgust stimuli used in the functional localizer for disgust

2.6 Participants & procedure

Twenty-six healthy volunteers (14 female, 12 male; aged between 18 and 35 years (*M* = 23.04, *SD* = 4.47)) participated in this study that was approved by the local ethical committee. Participants were recruited via general advertising on campus. Inclusion criterion was that participants had to be aged between 18 and 35 years. Exclusion criteria were the usual exclusion criteria due to technical and medical limitations (no implants; no large tattoos in the region of head, neck, shoulder and upper back; no claustrophobia; no current medication). In addition, people who participated in previous studies featuring the same or similar stimulus material (Study 1 and Study 3 in this dissertation) were not eligible to take part in this study, because they would no longer be blind to the hypotheses. All 26 participants did not suffer from neurological or psychiatric diseases as ensured by previous e-mail based screening. Twenty-four participants were right-handed and two left-handed. Two data sets were excluded due to data loss or wrong phase encoding, respectively. Among the remaining 24 subjects, two subjects chose to interrupt the scanning procedure after the third and the fifth session, respectively, due to feelings of oppression. For those participants only the fully completed sessions were entered into data analysis. Most of participants were students (*n* = 23) who received extra credit (hourly credit as a trial subject). Non-student participants (*n* = 3) were reimbursed with 40 Euros.

Upon arrival participants were instructed and signed informed consent. Before starting the scanning procedure, participants trained how to use the response device used in the scanner. They completed a series of rating tasks and a series of choice tasks. These rating and choice tasks used different pictures as subsequently used in the scanner. In the following, participants were prepared for the scanner and then completed the six experimental sessions in the scanner. After the fMRI session, participants completed a questionnaire which will be described in more detail in the following. After finishing the questionnaire, participants were debriefed, reimbursed and thanked for their participation.

2.8 Questionnaire

During the questionnaire participants were presented with all pictures which were used in the experimental paradigm. Each picture was presented for two seconds and the participants were then asked whether they had seen a human or a robot on the picture.

2.9 Behavioral data analysis (rating data and choice data)

Mean scores were calculated for the ratings of the robots with regard to how likable, familiar and human-like they were perceived. Moreover, mean score were calculated for the six stimuli categories with regard to likability, familiarity and human-likeness. To be able to relate ratings on likability, familiarity and human-likeness of specific stimuli to participants' decisions in favour or against these stimuli three additional variables were calculated: the relative difference in perceived likability ($\Delta\text{likable}_{rel}$), the relative difference in perceived familiarity ($\Delta\text{familiar}_{rel}$) and the relative difference in perceived human-likeness ($\Delta\text{human-like}_{rel}$). These three variables, $\Delta\text{likable}_{rel}$, $\Delta\text{familiar}_{rel}$, $\Delta\text{human-like}_{rel}$, were calculated for each decision trial in each subject with respect to the second stimulus by subtracting the mean likable/familiar/human-like rating for a specific stimulus that was shown first from the mean likable/familiar/human-like rating given to the second stimulus. The ratings used for this procedure were the mean ratings for a given stimulus obtained during the valuation task. For example, if the first stimulus received a mean likability rating of 1.5 in the valuation task, and the second stimulus received a mean likability rating of 0.5, the decision variable $\Delta\text{likable}_{rel}$ for that trial corresponded to −1.0. (The corresponding value for the variable $\Delta\text{likable}_{abs}$, i.e. the absolute, unsigned difference used for the fMRI regression analysis would be scored as+1.0.). Thus, $\Delta\text{likable}_{rel}=\text{likable}_{stimulus2}–\text{likable}_{stimulus1}$, where $\text{likable}_{stimulus2}$ and $\text{likable}_{stimulus1}$ are the average likability ratings given to the second and first stimulus, respectively; $\Delta\text{familiar}_{rel}=\text{familiar}_{stimulus2}–\text{familiar}_{stimulus1}$, where $\text{familiar}_{stimulus2}$ and $\text{familiar}_{stimulus1}$ are the average familiarity ratings given to the second and first stimulus, respectively; and $\Delta\text{human-like}_{rel}=\text{human-like}_{stimulus2}–\text{human-like}_{stimulus1}$, where $\text{human-like}_{stimulus2}$ and $\text{human-like}_{stimulus1}$ are the average human-likeness ratings given to the second and first stimulus, respectively.

The relative (i.e. signed) differences in perceived likability, familiarity and human-likeness were used for behavioral analysis. The absolute (i.e. unsigned) differences were used as regressors for neural activity. These absolute differences were defined as $\Delta likable_{abs}=|\Delta likable_{rel}|$, $\Delta familiar_{abs}=|\Delta familiar_{rel}|$ and $\Delta human\text{-}like_{abs}=|\Delta human\text{-}like_{rel}|$. This overall procedure of using averages for behavioral analysis and trial-by-trial ratings to construct parametric fMRI regressors follows standard approaches used in previous studies (cf. Grabenhorst et al., 2013).

Choices were counted and a ratio was calculated indicating which of the stimuli was preferably chosen by participants for each planned contrast. Decision confidence was calculated for each of the nine planned contrasts.

2.10 Functional MRI data acquisition and analysis

2.10.1 Functional MRI Data Acquisition

Functional MRI scanning was performed with a 7-Tesla whole-body MRI system (Magnetom 7T, Siemens Healthcare, Erlangen, Germany) at the Erwin L. Hahn Institute for Magnetic Resonance Imaging, Essen, Germany. The system is equipped with the SC72 gradient system capable of 70 mT/m maximum amplitude and a slew rate of 200 mT/m/ms. For this experiment, the scanner was equipped with a 1 channel transmit/ 32-channel receive head coil (Nova Medical, Wilmington, MA, USA). For each participant, a T1-weighted high-resolution anatomical scan (same slice prescription as EPI) and magnetization-prepared rapid-acquisition gradient echo (MPRAGE) were acquired for registration purposes (TR=2500 ms, TE=1.27 ms, TI=1100 ms, flip angle=7°, Field of View (FOV)=270*236 mm², matrix=394 x 345, sagittal plane, slice thickness = 0.7 mm, 256 slices with a non-interpolated voxel size of $0.7\times0.7\times0.7$ mm^3).

For the acquisition of functional images, subjects were scanned in six subsequent sessions, each lasting about 12 min to acquire a total of 2022 volumes (session1: 335; session2: 342; session3: 343; session4: 331; session5: 333; session6: 338). In addition, subjects were scanned during two functional localizer tasks, each lasting about 90 seconds to acquire a total of 73 volumes (localizer disgust: 33, localizer fusiform face area: 40). Whole-brain functional T2*-weighted echoplanar images (EPI) were acquired with an bold contrast-sensitive EPI sequence (c.f. Poser & Norris, 2009a; Poser & Norris, 2009b) optimized for 7.0-T (slice thickness, 1.51 mm; 144 coronal slices; TR=2000 ms; TE=22 ms; flip angle, 14°; matrix, 170 x 170; Field of View (FOV), 256 * 256 mm², order of acquisition of slices: interleaved).

As head coil array allows massive parallel imaging, the GRAPPA (Generalized Autocalibrating Partially Parallel Acquisitions) algorithm was used with a reduction factor of

R=9 to reconstruct the undersampled k-space (Griswold et al., 2002). Additionally, B_0 fieldmaps were acquired prior to the EPI-sequence to correct for geometric distortions in EPI images caused by magnetic field inhomogeneities.

2.10.2 Data analysis: Preprocessing

Functional images were analyzed using MATLAB R2011b (The MathWorks, Inc) and Statistical Parametric Mapping (SPM8, Wellcome Department of Imaging Neuroscience, London, UK; http://www.fil.ion.ucl.ac.uk/spm) for all imaging, pre-processing, and voxel-based statistical analyses within the context of the general linear model. During preprocessing EPI volumes were realigned to the first volume for each subject to correct for interscan movement, unwarped for movement-induced inhomogeneities and resliced with sinc interpolation. The high-resolution structural image was co-registered with the mean image of the EPI series. To reduce anatomical differences volumes were stereotactically normalized to the Montreal Neurological Institute (MNI) brain using the default SPM8 settings for normalization. To improve the signal and anatomical conformity, spatial smoothing was performed using a Gaussian kernel of 5 mm full width at halfmaximum. Time series non-sphericity at each voxel was estimated and corrected for, and a high-pass filter with a cut-off period of 128 s was applied.

2.10.3 Data analysis: General Linear Models

General linear models (GLMs) were applied to the time course of activation, where stimulus onsets were modeled as single-impulse response functions convolved with the canonical hemodynamic response function. Time derivatives were included in the basis functions set. Linear contrasts of parameter estimates were defined to test specific effects. Voxel values for each contrast resulted in a statistical parametric map of the corresponding t statistic. In the second (group random-effects) stage, subject-specific linear contrasts of these parameter estimates were entered into one-sample t-tests resulting in group-level statistical parametric maps. This analysis was conducted to identify significant differences between BOLD (Ogawa, Lee, Kay, & Tank, 1990) responses for the planned linear contrast between the conditions.

In GLM1, rating task trials were modeled with an indicator function for the onset of the stimulus picture which was parametrically modulated by the trial-specific likability, familiarity and human-likeness ratings. Separate indicator functions were included for the onset of the three rating scales which occurred later in the trial. Choice task trials were modeled with an indicator function for the onset of the first stimulus picture, an indicator function for the onset of the second stimulus picture modulated by trial-specific relative difference variables $\Delta likable_{abs}$, $\Delta familiar_{abs}$, and $\Delta human\text{-}like_{abs}$, and the trial-specific confidence rating, and separate indicator functions for the onset of the choice response period and the confidence ratings scale that occurred later in the trial. Movement parameters resulting from the realignment pre-processing step were included as covariates of no interest as well as six indicator functions for the different sessions.

In GLM2, rating task trials were modeled with an indicator function for the onset of the stimulus picture, with separate indicator functions for the six picture categories. No parametric modulators were used. As in GLM1, separate indicator functions were included for the onset of the three rating scales which occurred later in the trial. Choice task trials were modeled with an indicator function for the onset of the first stimulus picture, an indicator function for the onset of the second stimulus picture, with separate indicator functions for the nine picture contrasts. No parametric modulators were used. As in GLM1, separate indicator functions were included for the onset of the choice response period and the confidence ratings scale that occurred later in the trial. Movement parameters resulting from the realignment pre-processing step were included as covariates of no interest as well as six indicator functions for the different sessions.

2.10.4 Brain areas of interest and criteria for statistical significance

Only results for effects that survived whole-brain correction for multiple comparisons ($p<0.05$, corrected for family-wise error at the cluster level) are reported. The corrected cluster size threshold for whole brain corrections was determined using the function CorrClusTh.m (retrieved from http://www-personal.umich.edu/~nichols/JohnsGems5.html; provided by Thomas Nichols). The cluster threshold sizes determined this way ranged from 223 to 274 voxels, depending on the specific statistical map.

Brain areas of interest were the *fusiform gyrus* (fusiform face area) which is involved in face recognition (Chaminade et al., 2010; Cheetham et al., 2013; Courtney et al., 1997; Dubal et al., 2011; Gobbini et al., 2011; Kanwisher et al., 1997; Puce et al., 1995; Puce et al., 1996; Sergent et al., 1992), areas involved in social cognition such as the *precuneus*, the *posterior cingulate cortex* and *retrosplenial cingulate cortex*, the *anterior cingulate cortex*, the *dorsomedial and ventromedial prefrontal cortex*, the *posterior superior temporal sulcus*, the *temporoparietal junction* (cf. Amodio & Frith, 2006; Behrens, et al., 2009; Saxe, 2006), areas involved in monitoring reward and punishment such as the *orbital medial prefrontal cortex*, the *amygdala*, *ventral striatum* and *anterior cingulate cortex sulcus* (cf. Behrens, et al., 2009;

Grabenhorst et al., 2013), and areas involved in the perception and experience of disgust such as the *amygdala* and *insula* (cf. Calder et al., 2007; Jabbi et al., 2008; Koenigs, 2013; Wicker et al., 2003; Wright et al., 2004). In addition, the lateral prefrontal cortex and anterior temporal lobule were included.

The presently reported results focus on whole-brain corrected effects. In further, extended analyses, we will examine effects in these regions of interest.

3. Results

3.1 Behavioral data

Statistical analyses were performed using IBM SPSS for Windows (Release 20.0; August 16th, 2011; SPSS Inc. IBM, Chicago). Kolmogorov-Smirnov tests were calculated to test for normal distribution. For normal distributed data parametric tests like *ANOVAs* and *t* tests were used for further analysis. Data deviating significantly from normal distribution were subject to non-parametric tests. An alpha level of .05 was used for all statistical tests. For curve fitting and model selection RStudio (Release v0.97; May 11th, 2013; RStudio Inc., Boston) was used with the qpcR package for model fitting and model selection (Release 1.7; April 18th, 2013; Andrej-Nikolai Spiess).

3.1.1 Evaluation of robots

Mean scores were calculated for the ratings of the robots with regard to how likable, familiar and human-like they were perceived. The most and least likable, familiar and human-like robots are presented in Tables 44-46.

Table 44: Most and least likable humans and robots

Most Likable		Least Likable	
	M (SD)		M (SD)
HH2	4.21 (0.48)	RH4	2.30 (0.58)
HH5	4.11 (0.63)	HA5	2.40 (0.49)
HH4	4.00 (0.82)	RA4	2.40 (0.54)
HH3	3.82 (0.60)	HA6	2.41 (0.58)

Table 45: Most and least familiar humans and robots

Most familiar		Least familiar	
	M (SD)		M (SD)
HH4	4.20 (0.43)	RH1	2.36 (0.65)
HH2	4.15 (0.39)	RM3	2.36 (0.53)
HH5	4.05 (0.47)	RH4	2.38 (0.70)
HH3	3.96 (0.55)	RM2	2.47 (0.63)

Table 46: Most and least human-like humans and robots

Most human-like		Least human-like	
	M (SD)		M (SD)
HH5	4.69 (0.30)	RM3	1.88 (0.44)
HH2	4.65 (0.29)	RH1	1.92 (0.49)
HH3	4.64 (0.31)	RM1	1.93 (0.48)
HH4	4.63 (0.27)	RM2	2.02 (0.63)

Moreover, mean scores were calculated for all six stimuli of each of the six categories (healthy, disabled, and artificial humans, and android, humanoid, and mechanoid robots).

Repeated measures ANOVAs for the six stimulus categories were conducted with Bonferroni correction for multiple comparisons and the ratings for likable, familiar and human-like as dependent variables. Results showed that the six groups differed significantly from each other with regard to their likability ($F(1; 25) = 52.43$; $p < .001$; $\eta^2 = .68$), familiarity ($F(1; 25) = 63.97$; $p < .001$; $\eta^2 = .72$) and human-likeness ($F(1; 25) = 137.53$; $p < .001$; $\eta^2 = .85$, cf. Table 47).

Pairwise comparisons for likability showed that healthy humans and disabled humans were significantly more likable than artificial humans and all three robot groups. Healthy humans were also more likable than disabled humans. Android robots were significantly more likable than artificial humans. There were no differences between the three robot groups (for mean values and results of post hoc analysis cf. Table 66 in Appendix C).

The pairwise comparisons for familiarity revealed that again healthy humans and disabled humans were more familiar than artificial humans and all three robot groups. Furthermore, healthy humans were more familiar than disabled humans. Android robots were significantly more familiar than mechanoid robots. There were no differences between artificial humans and the three robot groups.

With regard to human-likeness the pairwise comparisons showed that healthy humans were also significantly more human-like than disabled and artificial humans and all three robot groups (supporting ***H1b***). Disabled humans were more human-like than artificial humans and all robot groups. There were no differences with regard to human-likeness between artificial humans and android robots, but both groups were significantly more human-like than humanoid and mechanoid robots (partial support for ***H1a***). There were no significant differences between humanoid and mechanoid robots.

Table 47: Mean values and standard deviations and post hoc comparisons for likability, familiarity and human-likeness ratings for all six stimulus categories

	healthy humans	**disabled humans**	**artificial humans**	**android robots**	**humanoid robots**	**mechanoid robots**	
	M (SD)	*M (SD)*	*M (SD)*	*M (SD)*	*M (SD)*	*M (SD)*	*Post hoc*
likable	3.92 (0.39)	3.32 (0.50)	2.55 (0.44)	2.84 (0.31)	2.68 (0.30)	2.81 (0.54)	1>2>3-6; 4>3; 3=5=6; 4=5=6
familiar	3.99 (0.31)	3.14 (0.54)	2.76 (0.61)	2.85 (0.40)	2.62 (0.47)	2.59 (0.41)	1>2>3-6; 4>6; 5=6; 3=4,5,6;
human-like	4.59 (0.24)	4.16 (0.34)	3.45 (0.64)	3.46 (0.50)	2.37 (0.52)	2.06 (0.42)	1>2>3-6; 3=4>5=6

Besides the evaluations during the experimental paradigm, participants were asked after the scanning session, to indicate whether the pictures they saw were showing robots or humans. Thus, for each of the six stimuli in one of the six categories the participants had to decide whether the picture shows a human or a robot resulting in a total of 156 decisions per category. With regard to the healthy humans, participants overall correctly identified them as humans (answers: 155 human, 1 robot). The disabled humans were also overall correctly classified as humans (answers: 154 human, 2 robot). Participants were also overall correct in their decisions with regard to the humanoid robots (answer: 2 human; 154 robot) and mechanoid robots (answer: 1 human; 155 robot). However, with regard to the android robots and the artificial humans participants had difficulties to classify these stimuli correctly as humans or robots. The android robots were still more often classified as robots (answer: 63 human; 93 robot). But the artificial humans were also classified more often as robots than as humans (answer: 67 human; 89 robot).

3.1.2 Relationship of human-likeness, likability and familiarity

To test the hypothesis that ratings on *human-likeness* predict (***H2***) *likability* and *familiarity* ratings mean values for all three items for each of the 36 human and robotic stimuli were calculated. Human-likeness predicted participants' likability and familiarity ratings.

Likability. Human-likeness significantly predicted likability scores, β= .72, $t(34) = 6.06$, $p <$ .001. Human-likeness also explained a significant proportion of variance in likability scores, $R^2 = .52$, $F(1, 35) = 36.68$, $p < .001$.

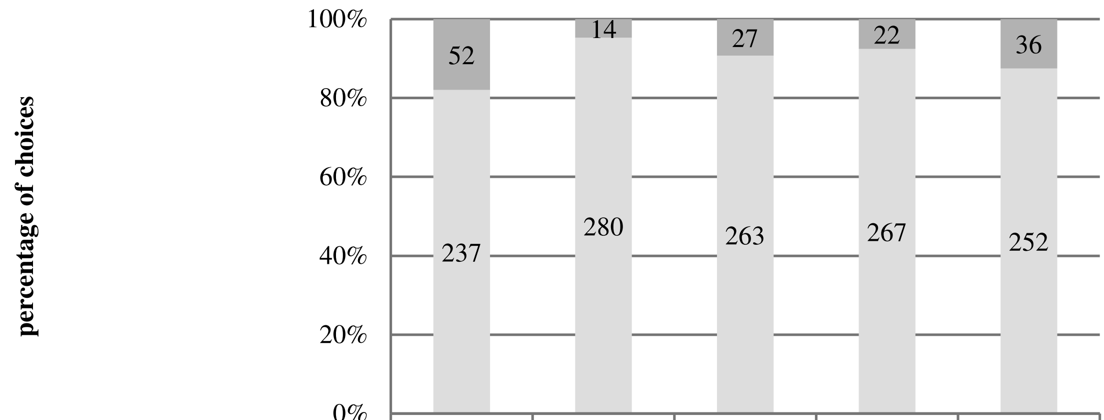
Familiarity. Human-likeness significantly predicted familiarity scores, β= .85, $t(34) = 8.53$, p < .001. Human-likeness also explained a significant proportion of variance in familiarity scores, $R^2 = .68$, $F(1, 35) = 72.73$, $p < .001$.

3.1.2 Choices

Participants had to make in total 108 choices. Within the choice trials participants were presented with two stimuli which were implemented according to the nine contrasts between the six categories of stimuli (cf. Section VI.2.4). Choices were counted and a ratio was calculated indicating which of the stimuli was preferably chosen by participants.

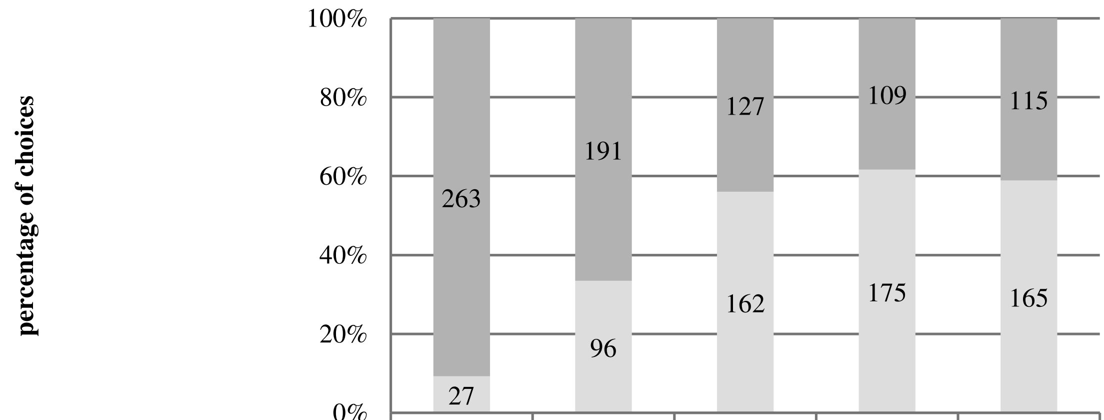
When comparing the category of healthy humans with the five other categories, participants tended to choose in favor for the healthy humans (supports ***H3a***). Ratios in favor for the healthy humans were between 82% (contrast healthy human vs. disabled human) and 95% (contrast healthy human vs. artificial human). For the total number of choices and the ratios cf. Figure 53. The probability for choices in favor for humans were significantly different from chance (cf. Table 48).

The comparison of the category of android robots with the five other categories showed that participants tended to choose in favor for the healthy and disabled humans, but not in favor for the artificial humans or humanoid and mechanoid robots. Ratios in favor for the android robots were between 10% (contrast android robot vs. healthy human) and 61% (contrast android robot vs. humanoid robot). For the total number of choices and the ratios cf. Figure 54. The probability for choices in favor for the android robots were significantly different from chance (cf. Table 48).



	healthy human vs. disabled human	healthy human vs. artificial human	healthy human vs. android robot	healthy human vs. humanoid robot	healthy human vs. mechanoid robot
choices in favor for counterpart	52	14	27	22	36
choices in favor for healthy human	237	280	263	267	252

Figure 53: Total number and percentage of choices comparing healthy humans with disabled and artificial humans and android, humanoid and mechanoid robots



	android robot vs. healthy human	android robot vs. disabled human	android robot vs. artificial human	android robot vs. humanoid robot	android robot vs. mechanoid robot
choices in favor for counterpart	263	191	127	109	115
choices in favor for android robot	27	96	162	175	165

Figure 54: Total number and percentage of choices comparing android robots with healthy, disabled and artificial humans and humanoid and mechanoid robots

Table 48: Binominal test results for the choices in the nine planned contrasts

	Percentage of choices in favor for healthy human	CI	*p*
HH vs. HD	82%	0.78; 0.87	< .001
HH vs. HA	95%	0.92; 0.97	< .001
HH vs. RA	90%	0.87; 0.94	< .001
HH vs. RH	92%	0.88; 0.95	< .001
HH vs. RM	88%	0.84; 0.92	< .001
	Percentage of choices in favor for android robot	**CI**	***p***
RA vs. HD	33%	0.28; 0.39	< .001
RA vs. HA	56%	0.38; 0.50	.04
RA vs. RH	61%	0.56; 0.67	< .001
RA vs. RM	58%	0.52; 0.65	.003

Moreover, mean scores were calculated for the choice confidence ratings for all nine contrasts of the six categories (cf. Table 49 for mean values and standard deviations). A repeated measure ANOVA for the nine contrasts was conducted with Bonferroni correction for multiple comparisons and the confidence ratings as dependent variable. Results showed that the nine contrasts differed significantly from each other with regard to participants confidence in their decision ($F(8; 35) = 31.58$; $p < .001$; $\eta^2 = .568$) cf. Table 49).

Table 49: Mean values and standard deviations for participants confidence ratings for all six stimulus categories

	HH vs. HD *M (SD)*	HH vs. HA *M (SD)*	HH vs. RA *M (SD)*	HH vs. RH *M (SD)*	HH vs. RM *M (SD)*	RA vs. HD *M (SD)*	RA vs. HA *M (SD)*	RA vs. RH *M (SD)*	RA vs. RM *M (SD)*
confidence rating	3.48 (0.59)	4.00 (0.52)	4.00 (0.43)	4.02 (0.47)	4.01 (0.44)	3.45 (0.38)	3.09 (0.44)	3.17 (0.37)	3.39 (0.38)

Note: HH = human healthy, HD= human disabled, HA= human artificial, RA=robot android, RH= robot humanoid, RH= robot mechanoid

Pairwise comparisons showed that participants were least confident in their decision when choosing between android robots and artificial humans and between android robots and humanoid robots. There were no significant differences between these two and the contrasts healthy humans versus disabled humans and android robots versus disabled humans (HH-HD = RA-HD = RA-HA = RA-RH). However, the mean RA-HA confidence ratings were significantly lower than all other four mean confidence ratings involving healthy humans

(HH-RA, HH-HA, HH-RH, HH-RM) and the contrast android robot versus mechanoid robot. Participants were most confident in their decisions when healthy humans were compared to artificial humans and all three types of robots (partial support for ***H3b***). There were no significant differences in their mean confidence ratings between these for contrasts (HN-RA = HN-HA = HN-RH = HN-RM), which were, however, all significantly higher than the confidence ratings for the contrasts healthy human vs. disabled human, android robot vs. disabled human, artificial human, mechanoid robot and humanoid robot (HN-RA, HN-HA, HN-RH, HN-RM > HN-HD, RA-HD, RA-HA, RA-RM, RA-RH; for mean values and results of post hoc analysis cf. Table 67 in Appendix C).

To examine whether trial-wise rating differences with regard to likability, familiarity and human-likeness (***H4a-H4c***) between two stimuli predict participants' choice, choice data was analyzed using logistic regression analysis (Howell, 2010) with subject treated as a random factor (*n*=2245 choices). The three variables, Δlikebale$_{rel}$, Δfamiliar$_{rel}$ and Δhuman-like$_{rel}$, were related to the probability of choosing the second stimulus on each trial using logistic regression analysis with Δlikebale$_{rel}$, Δfamiliar$_{rel}$ and Δhuman-like$_{rel}$ as regressors in the same model.

Results showed that trial-wise rating differences with regard to all three variables –likability, familiarity and human-likeness- were predictive for participants' choice between the two stimuli. The more participants' evaluation was in favor for the second stimulus (indicated by positive and higher values in Δlikebale$_{rel}$, Δfamiliar$_{rel}$ and Δhuman-like$_{rel}$), the likely participants' chose in favor for the second stimulus (first stimulus coded as 1, second coded as 0, thus the relation is negative; cf. Table 50-52).

Table 50: Logistic regression for choosing the second stimulus with the predictor Δlikable

		95% CI for Odds Ratio		
	B (SE)	Lower	Odds Ratio	Upper
Included				
Constant	.143* (.06)			
Δlikable	-1.859** (.08)	0.13	0.17	0.18

Note: R^2=.43 (Hosmer & Lemeshow); .45 (Cox & Snell), .60 (Nagelkerke). Model $x^2(1)$ =1330.69, *p* <001. **p<.05** p<.001*

Table 51: Logistic regression for choosing the second stimulus with the predictor Δfamiliar

		95% CI for Odds Ratio		
	B (SE)	Lower	Odds Ratio	Upper
Included				
Constant	-.154* (.07)			
Δfamiliar	-1.627** (.07)	0.17	0.20	0.23

Note: R^2=.38 (Hosmer & Lemeshow); .42 (Cox & Snell), .55 (Nagelkerke). Model $x^2(1)$ =1186.67, $p < .001$. **p<.05** p<.001*

Table 52: Logistic regression for choosing the second stimulus with the predictor Δhuman-like

		95% CI for Odds Ratio		
	B (SE)	Lower	Odds Ratio	Upper
Included				
Constant	-.137* (.04)			
Δhuman-like	-.941** (.05)	0.36	0.39	0.42

Note: R^2=.27 (Hosmer & Lemeshow); .31 (Cox & Snell), .42 (Nagelkerke). Model $x^2(1)$ =832.54, $p < .001$. **p<.05** p<.001*

3.1.3 Reproducing the uncanny valley

In order to answer ***RQ6*** it was examined which mathematical function (linear, quadratic, cubic) fits best to the obtained data with regard to the relation of human-likeness and likability and human-likeness and familiarity, respectively.

For the relation of subjective ratings on *human-likeness* and *likability* of the pictures presented the cubic function showed the lowest AICc value and a delta smaller than 2 (Δ_i <2) suggesting high goodness-of-fit and substantial evidence for the cubic model. The quadratic model received less support indicated by a delta of 4.34 (less support for 3< Δ_i <7). Lastly, the linear model was rather unlikely as indicated by the rather large delta of 31.8 (very unlikely if Δ_i >10). When comparing the cubic and quadratic model (w_{cubic}(AIC)/ $w_{quadratic}$(AIC) =2.20) the evidence ratio was smaller than 2.7. Hence, the cubic and quadratic model can be regarded as statistically equivalent in which case the principle of parsimony would suggest to stick with the simpler model which would be the quadratic model. Moreover, all three models were within the confidence set, because their Akaike weights were higher than the 10% cut off value of the highest Akaike weight (.95, cf. Table 53). Thus, also the linear model was suited to explain the data which is also reflected in the regression model reported in section VI.3.1.2. Figure 55 shows the estimated model curves for all three models.

Table 53: Akaike's second-order information criterion (AICc) of the models human-likeness x likability and human-likeness x familiarity

	model	*log-likelihood*	*RSS*	AIC_c	$\Delta_i\,(AIC)$	$w_i\,(AIC)$	R^2	*CI*
likable	linear	1.25	16.84	81.17	31.80	1.19	.52	.95
	quadratic	4.54	7.74	55.56	6.18	4.34	.78	-
	cubic	**1.00**	**5.18**	**49.37**	**0.00**	**9.57**	**.83**	**-**
familiar	linear	2.40	11.15	66.33	44.30	2.39	.68	.99
	quadratic	7.24	6.07	41.09	19.06	7.24	.85	-
	cubic	**1.00**	**2.84**	**22.03**	**0.00**	**9.99**	**.92**	**-**

Note: best model in boldface

For the relation of subjective ratings on *human-likeness* and on *familiarity* of the pictures presented again the cubic function showed the lowest AICc value and a delta smaller than 2 (Δ_i <2) suggesting substantial evidence for this model. The linear and quadratic model seemed rather unlikely as indicated by the rather large deltas (very unlike if Δ_i >10). However, when comparing the quadratic and cubic models, the evidence ratio was smaller than 2.7 (w_{cubic}(AIC)/ $w_{quadratic}$(AIC) =1.37). Hence, the models can be regarded as statistically equivalent in which case the principle of parsimony suggests to stick with the simpler model which is the quadratic model. Moreover, all three models were within the confidence set, because their Akaike weights were higher than the 10% cut off value of the highest Akaike weight (.99, cf. Table 53), thus, also the linear model was suited to explain the data (cf. results in section VI.3.1.2). Figure 56 shows the estimated model curves for all three models.

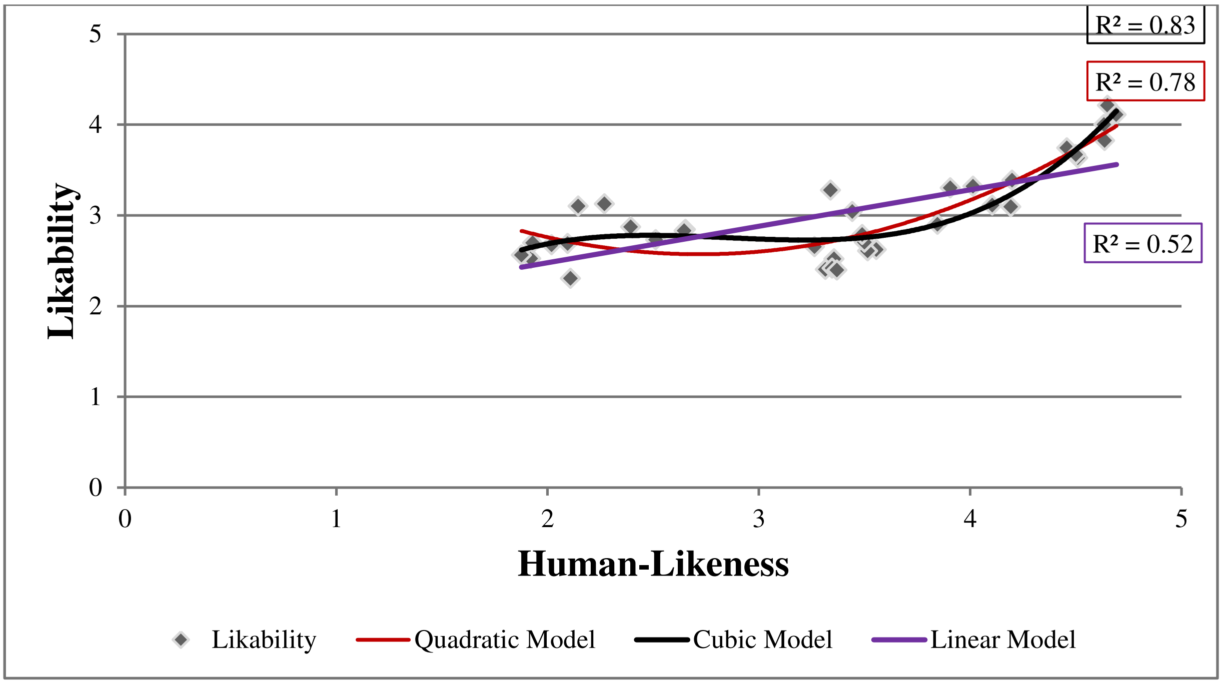


Figure 55: Scatterplots for the human-likeness ratings with the ratings on likability including the graphical depiction of the three model curves (linear, quadratic, cubic)

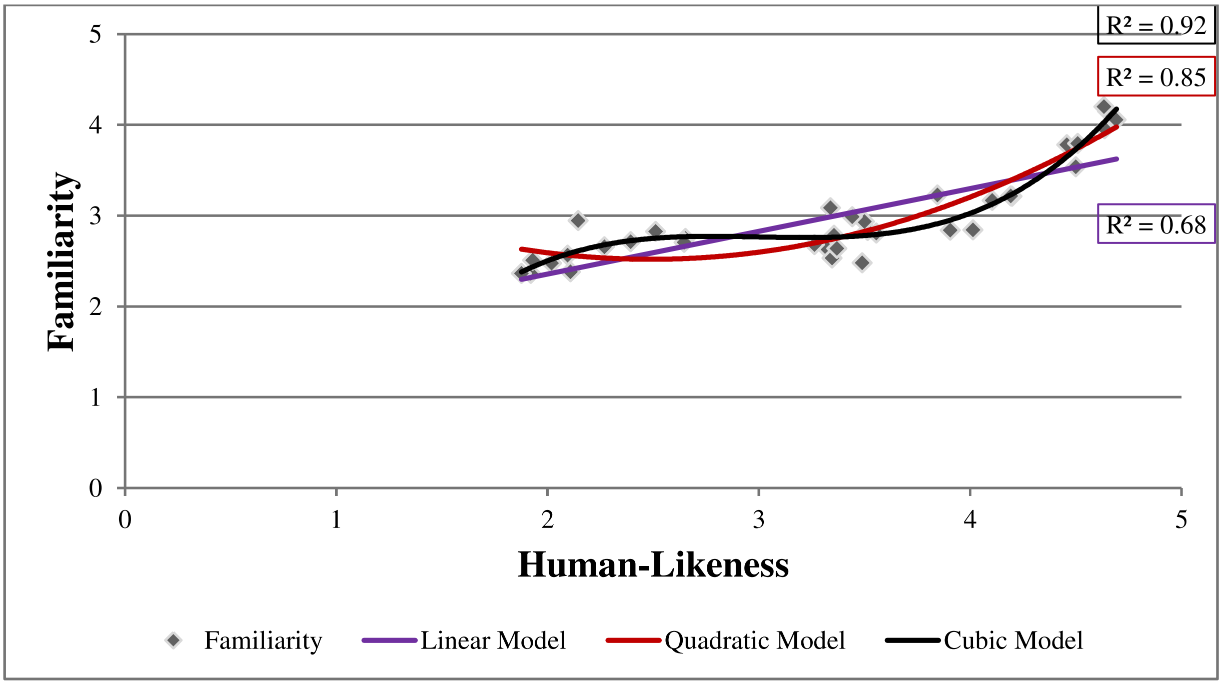


Figure 56: Scatterplots for the human-likeness ratings with the ratings on familiarity including the graphical depiction of the three model curves (linear, quadratic, cubic)

3.2 Imaging data

Functional images were analyzed using MATLAB R2011b (The MathWorks, Inc) and Statistical Parametric Mapping (SPM8, Wellcome Department of Imaging Neuroscience, London, UK; http://www.fil.ion.ucl.ac.uk/spm). Region-of-interest analyses were performed using the MarsBar toolbox for SPM8 (Brett, Anton, Valabregue, & Poline).

3.2.1 Evaluation of humans and robots

With regard to the evaluation of humans and robots it was asked whether brain areas can be identified which are involved in the evaluation in terms of likability, familiarity, and human-likeness. Therefore, to examine relationships between neural activity and participants' rating behavior, neural activity at the time of rating was regressed against participants' actual ratings with regard to likability, familiarity and human-likeness (***RQ1***). It was found that activity in the left and right fusiform gyrus was negatively correlated to ratings in human-likeness (cf. Table 54). Hence, participants rated the stimuli less humanlike when activity in the fusiform gyri was high. There were neither effects found for the relationship of neural activity and ratings on familiarity, nor for the relationship of neural activity and ratings on likability.

Moreover, relationships between neural activity and trial-wise ratings differences between two stimuli which were presented together in the decision trials were examined (***RQ2***). No correlations were found (cf. Table 54).

Table 54: Significant results for the fMRI analyses in brain areas with apriori hypotheses in GLM1 – whole brain corrected, corrected for family-wise error at the cluster level, MNI coordinates

GLM1	**brain area**	**L.**	**cluster size**	**x**	**y**	**z**	**peak *T*-value**	**peak *z*-score**	***p* FEW corr**
likable correlation	-	-	-	-	-	-	-	-	-
familiar correlation	-	-	-	-	-	-	-	-	-
human-like correlation: negative	Fusiform gyrus	R	543	28	-66	-12	6.57	4.74	<0.001
	Fusiform gyrus	L	730	-26	-78	-16	6.42	4.68	<0.001
Δ likable correlation	-	-	-	-	-	-	-	-	-
Δ familiar correlation	-	-	-	-	-	-	-	-	-
Δ human-like correlation	-	-	-	-	-	-	-	-	-

The functional localizer for the fusiform face area (FFA) could not be used to identify this specific area due to technical problems. Thus, a comparison with results of previous work is needed in order to identify whether the activation in the fusiform gyrus corresponds to the FFA as found in previous studies (cf. Table 55). The coordinates for the human-like correlation in the medial fusiform gyrus are very similar to those obtained by Gobbini et al. (2011) for the comparison of robot stimuli to resting state and for the comparison of robotic to human stimuli, as well as the coordinates reported by Chaminade et al. (2010) for the comparison of human to robotic stimuli. They differ, however, from the coordinates reported by Gobbini et al. (2011) for the comparison of solely human stimuli with resting state (which marked a more lateral and posterior area in the fusiform gyrus), and those reported by Kanwisher et al. (1997, which were also more lateral and posterior). Results suggest that the neural activity which was found to be correlated with lower ratings in human-likeness recruits a distinct sub area of the fusiform gyrus which previously has been found to be active when comparing human and robot stimuli.

Table 55: MNI coordinates for fusiform gyrus activation in previous work in comparison with current findings

study	left			Right			stimuli	task
	x	y	z	x	y	Z		
current study: negative human-like correlation	-26	-78	-16	28	-66	-12	pictures of humans and robots	passive viewing
Kanwisher et al., 1997*	-35	-64	-16	40	-56	-15	pictures of (scrambled) faces, objects, houses	passive viewing
Chaminade et al., 2010	-34	-62	-18	42	-60	-20	videos of human faces, robot faces	passive viewing
Gobbini et al., 2011*	-35	-47	-24	38	-47	-25	videos of human faces vs. resting state	passive viewing
	-28	-70	-17	29	-49	-20	videos of robotic faces vs. resting state	passive viewing
	-30	-61	-18	27	-77	-24	comparison human/robotic faces	passive viewing
Cheetham et al., 2011	-46	-58	-18	42	-52	-18	diverse human stimuli	discriminate
	-	-	-	38	-36	-30	diverse avatar stimuli	discriminate

*reported Talairach space coordinates have been transferred to the MNI space using Brett's mni2tal equation

3.2.1 Decision behavior, decision uncertainty and relationship of evaluations and decisions

With regard to the decision task, it was firstly examined whether different neural activity can be observed during the two tasks – rating and decision-making (***RQ3***). Thus, neural activity during ratings and neural activity during decision-making was contrasted. Results show that compared to the decision task there was more neural activity during the rating task in the fusiform gyrus (the coordinates correspond to the ones found for the negative human-like correlation) and the precuneus, both bilaterally. In contrast, there was more neural activity in the right inferior parietal lobule (in the area of the TPJ) and left superior parietal lobule, as well as left superior medial frontal gyrus during the decision task compared to the rating task (cf. Table 56).

To examine the relationship between neural activity and participants' experience during decision-making, neural activity at the time of choice was regressed against participants' confidence in that decision (***RQ4***). Results show that neural activity in the right subgenual ACC, the left insula, and the inferior parietal lobule (near the temporo-parietal junction) and precuneus, both bilaterally, was positively correlated to confidence ratings (cf. Table 56). Thus, participants had higher confidence in their decisions when activity in the aforementioned areas was high. Moreover, this finding is consistent with a previous study on odor pleasantness decisions (Rolls, Grabenhorst, & Deco, 2010) using the same fMRI decision task design: In that study subgenual ACC at coordinate [10 24 -8] was correlated with the absolute difference in the decision variable (difference in odor pleasantness between first and second odor) which indicates confidence.

Table 56: Significant results for the fMRI analyses in brain areas with apriori hypotheses in GLM1

GLM1	brain area	L.	cluster size	x	y	z	peak *T*-value	peak *z*-score	*p* FEW corr
ratepic > decpic2	Fusiform gyrus	R	598	26	-70	-10	8.34	5.41	<0.001
	Fusiform gyrus	L	550	-24	-76	-14	8.28	5.40	<0.001
	Precuneus	R	920	20	-72	46	6.40	4.67	<0.001
	Precuneus	L	527	-20	-56	26	5.19	4.08	<0.001
decpic2 > ratepic	TPJ	R	332	52	-58	36	8.16	5.36	0.010
	Superior parietal lobule	L	880	-8	-52	40	6.33	4.64	<0.001
	Superior medial frontal gyrus	L	454	-4	18	44	5.99	4.48	0.001
confidence correlation	Insula	L	343	-34	4	12	6.04	4.51	0.012
	Subgenual ACC	R	502	14	20	-16	5.44	4.21	0.001
	Inferior parietal lobule, TPJ	L	483	-60	-34	34	5.19	4.08	0.001
	Inferior parietal lobule, TPJ	R	427	54	-30	30	4.95	3.95	0.003
	Precuneus	L	312	-10	-64	20	5.05	4.01	0.021
	Precuneus	L	791	-2	-50	56	4.90	3.93	<0.001

These brain areas (ACC, Precuneus, TPJ) have frequently been found to be involved in mentalizing, empathy or theory of mind tasks. Thus, the coordinates found in this study were compared with those found in previous work (cf. Table 55). The precuneus and TPJ were particularly involved when comparing human and robotic stimuli in tasks requiring mentalizing such as the prisoners' dilemma and rock-paper-scissor playing showing that increased anthropomorphism of the game partner resulted in increased neural activity in the aforementioned areas (Krach et al., 2008; Chaminade et al., 2012). Indeed, the coordinates of the right TPJ activation during decision-making (decpic>ratepic contrast) are very similar to those found by Krach et al. (2008) and Chaminade et al. (2012). The activation of the inferior parietal lobule (near TPJ) for the confidence correlation, however, seems to be more anterior than the coordinates found in previous studies.

Table 57: MNI coordinates for TPJ activation in previous work in comparison with current findings

study	**Left**			**right**			**stimuli**	**task**
	x	**Y**	**z**	**x**	**y**	**z**		
current study: decpic2>ratepic	-	-	-	52	-58	36		
current study: confidence correlation	-60	-34	34	54	-30	30		
Krach et al., 2008*				56	-56	20	human-likeness dimension (computer<functional robot<anthropomorphic robot<human)	Prisoners dilemma
Chaminade et al., 2012				56	-54	28	Intentional agent > random agent	Rock-paper-scissor
				56	-52	16	Intentional agent > artificial agent	Rock-paper-scissor
Saxe & Wexler, 2005	-48	-69	21	54	-54	24	text	Mentalizing based on text

*reported Talairach space coordinates have been transferred to the MNI space using Brett's mni2tal equation

With regard to the precuneus, the activation in the right hemisphere during evaluation (ratepic>decpic contrast) and the activations in the left hemisphere for the confidence correlation are similar to those found by Krach et al. (2008) and Chaminade et al. (2012). The activation in the left hemisphere during evaluation, however, seems to be more dorsal than the coordinates found in previous studies (cf. Table 58).

Moreover, the question was posed whether the influence of trial-wise rating differences (with regard to likability, familiarity and human-likeness) between two stimuli on the decision for one of these stimuli is correlated with the effect size of the correlation between confidence ratings and neural activity in the left and right inferior parietal lobule, and the left and right precuneus (***RQ5***). In across-subject analyses, the magnitude of the neural effects was related to the behaviorally derived logistic regression betas. No significant relationship emerged for the three trial-wise ratings differences: Δlikable, Δfamiliar, Δhuman-like.

Table 58: MNI coordinates for precuneus activation in previous work in comparison with current findings

study	Left			right			stimuli	task
	x	Y	z	x	y	z		
current study: ratepic > decpic	-20	-56	26	20	-72	46		
current study: confidence correlation	-10	-64	20	-	-	-		
	-2	-50	56	-	-	-		
Krach et al., 2008*	-	-	-	8	-78	52	Computer > control	Prisoners dilemma
	-	-	-	8	-78	52	Functional robot > control	Prisoners dilemma
	-	-	-	8	-80	50	Anthropomorphic robot > control	Prisoners dilemma
	-	-	-	6	-76	52	Human > control	Prisoners dilemma
Chaminade et al.	-8	-64	52	-	-	-	Intentional agent > random agent	Rock-paper-scissor

*reported Talairach space coordinates have been transferred to the MNI space using Brett's mni2tal equation

3.2.1 Testing perception-oriented explanations: person perception

It has been shown that robotic or virtual faces elicited processes of face recognition in the fusiform gyrus similar to those elicited by human stimuli (Chaminade et al., 2010; Cheetham et al., 2011; Dubal et al., 2011; Gobbini et al., 2011) and it has been argued that additional processing is needed to code a robot face as a face. Thus, it was hypothesized that the perception of very human-like robots cause increased brain activity in the fusiform face area during rating trials. First, it has been assumed that there will be no differences in brain activity in the fusiform gyrus during the rating task between healthy humans and artificial humans, and no differences between healthy humans and disabled humans (***H5a***). While, indeed no effect emerged for the comparison of healthy and artificial humans, more activation in the fusiform gyrus was found for the contrast of disabled humans and healthy humans thereby only partially supporting the hypothesis (HD>HH, cf. Table 59). Interestingly, the coordinates of this effect correspond more to the activation for solely human stimuli in previous work (MNI coordinates 40, -52, -20 compared to, for instance, 40, -56, -15 in Kanwisher et al. 1997, cf. Table 55).

Moreover, it has been hypothesized that there will be increased brain activity in the fusiform gyrus when comparing robots with healthy humans (***H5b***). Partially confirming this hypothesis there was increased bilateral fusiform gyrus activation when comparing humanoid and mechanoid robots with healthy humans (RH>HH; RM>HH), but no difference when comparing android robots with healthy humans (RA>HH, cf. Table 59). The activations found for these contrast were more in the medial frontal gyrus and correspond to the coordinates found for the negative human-like correlation (cf. Table 55) and the coordinates found in previous work comparing robotic and human stimuli (Chaminade et al., 2010; Cheetham et al., 2011; Gobbini et al., 2011). Interestingly, a similar pattern of bilateral activation in the fusiform gyrus was found when comparing humanoid and mechanoid robots with android robots (RH>RA; RM>RA, cf. Table 59).

Lastly, it has been hypothesized that there will be increased brain activity in the fusiform gyrus when comparing android robots with disabled or artificial humans (***H5c***). Again, partically confirming the hypothesis, it was found that there were no differences when comparing android robots and disabled humans (RA>HD or HD>RA), but increased fusiform gyrus activity has been found for artificial humans contrasted to android robots (HA>RA). Similar to the contrast HD>HH, the coordinates of this effect correspond more to the activation for solely human stimuli in previous work.

Table 59: Significant results for the fMRI analyses in brain areas with apriori hypotheses in GLM2 – with regard to ratings

GLM2	brain area	lat.	cluster size	x	y	z	peak *T*-value	peak *z*-score	*p* FWE corr
Rating HH > HD	Precuneus, Cingulate gyrus	R	573	4	-74	24	6.04	4.51	<0.001
Rating HD > HH	Fusiform gyrus	R	346	40	-52	-20	4.99	3.98	0.008
Rating HH > HA	-	-	-	-	-	-	-	-	-
Rating HA > HH	-	-	-	-	-	-	-	-	-
Rating HH > RA	-	-	-	-	-	-	-	-	-
Rating RA > HH	-	-	-	-	-	-	-	-	-
Rating HH > RH	Precuneus	-	340	0	-58	36	5.58	4.28	0.006
Rating RH > HH	Fusiform gyrus	L	562	-28	-66	-10	6.91	4.88	<0.001
	Fusiform gyrus	R	524	28	-66	-10	6.64	4.77	<0.001
Rating HH > RM	Precuneus	R	327	2	-76	40	5.34	4.16	0.010
Rating RM > HH	Fusiform gyrus	L	475	-26	-88	-2	6.63	4.77	0.001
	Fusiform gyrus	R	513	26	-76	-8	5.32	4.15	<0.001
Rating RA > HD	-	-	-	-	-	-	-	-	-
Rating HD > RA	-	-	-	-	-	-	-	-	-
Rating RA > HA	Fusiform gyrus	R	323	40	-78	-14	6.33	4.64	0.010
	Fusiform gyrus	L	393	-34	-78	-14	6.01	4.49	0.003
Rating HA > RA	-	-	-	-	-	-	-	-	-
Rating RA > RH	-	-	-	-	-	-	-	-	-
Rating RH > RA	Fusiform gyrus	L	307	-28	-86	-12	5.81	4.40	0.014
	Fusiform gyrus	R	390	26	-72	-14	5.40	4.19	0.003
Rating RA > RM	Precuneus	L	276	-6	-60	38	5.57	4.28	0.025
Rating RM > RA	Fusiform gyrus	L	323	-22	-78	-14	4.96	3.96	0.010

3.2.1 Testing perception-oriented explanations: social cognition

It has been shown that increased anthropomorphism caused increased brain activity in areas relevant for ToM (e.g. Krach et al., 2008). Therefore, it was hypothesized that there will be increased brain activation in areas associated with ToM when comparing the human stimuli with the robotic stimuli during rating trials (***H6***). Similar to the findings concerning face perception, no differences were found when comparing healthy humans and android robots (HH>RA; RA>HH), but the contrast of healthy humans with humanoid and mechanoid robots (HH>RH; HH>RM) elicited increased reaction in the precuneus, an area which has been associated with theory of mind (cf. Table 59). Thus, the hypothesis was supported with regard to humanoid and mechanoid robots, but has to be rejected for android robots. Interestingly, there were also increased activation in the precuneus when comparing android robots with mechanoid robots (RA>RM, cf. Table 59). Moreover, it has to be noted that the comparison of healthy humans and disabled humans (HH>HD) resulted in increased activity in the precuneus as well as in the cingulate gyrus.

3.2.1 Testing evolutionary-biological explanations: disgust

Because very human-like robots might provide heuristic disease cues and thus elicit responses from the behavioral immune system, it has been hypothesized that disabled humans, artificial humans and android robots will elicit increased neural activity in the insula during rating trials in comparison to healthy humans (***H7***). No effects supporting this hypothesis have been found (cf. Table 54 & 56).

4. Discussion

The aim of this study was to test explanatory approaches for the uncanny valley. For this purpose an experimental paradigm has been developed which allowed to examine uncanny valley related reactions in participants' evaluations of humans and robots with regard to uncanny valley relevant rating dimensions (likability, familiarity, human-likeness) and regarding behavioral measures (decision making). Participants had to rate six categories of stimuli: healthy humans, disabled humans, artificial humans, android robots, humanoid robots and mechanoid robots. During the decision trials participants had to choose one of two presented stimuli with regard to the question from whom they would like to receive a reward (under the condition that several rewards can be given, every presented human or robot has chosen a reward prior to the experiment and this choice is unknown to the participants). Participants also reported how confident they were in their decisions. Furthermore, it was analyzed whether these behavioral effects could be explained by the proposed explanations.

More specifically, it was examined whether uncanny valley related effects occur due to a) additional processing during face perception of human and robotic stimuli, b) automatically elicited processes of social cognition, or c) oversensitivity of the behavioral immune system. Hence the relationship of behavioral effects and activity in relevant brain areas which were defined as region of interest based on theoretical considerations was analyzed.

4.1 Evaluation of humans and robots and the uncanny valley

In accordance with ***H1b*** it was found that healthy humans were rated as significantly more human-like than all other stimulus categories including disabled and artificial humans. The human and android robot stimuli were rated as more human-like than the humanoid and android robots. However, android robots and artificial humans did not differ in human-likeness (altogether only partial support for ***H1a***). This is also reflected in the result that participants reported the lowest confidence in their decisions when they had to decide between android robots and artificial humans. Moreover, participants showed least accuracy in their categorizations of artificial humans and android robots as either human or robot in the post-questionnaire. These findings are in some accordance with those from previous studies applying discrimination and identification tasks where category uncertainty at category boundaries was also demonstrated by decreased accuracy, and increased decision uncertainty (Cheetham et al., 2011; Cheetham et al., 2013; Yamada et al., 2013). Hence, it seems that in the present study android robots and artificial humans mark the category boundary between humans and robots. Since in this paradigm participants had to evaluate the stimuli rather quickly, it could be that the effects were due to the phenomenon of categorical perception (Harnad, 1990), although the results do not rule out that participants do not also employ generic knowledge categories (which also contain abstract bits of knowledge and beliefs of the world; Medin & Barsalou, 1990; cf. section II.4.3.1). Indeed, it has been argued that most generic knowledge categories include at least some perceptual features and the classification of generic knowledge categories "often appears to depend heavily on perceptual properties" (Medin & Barsalou, 1990, p. 456). However, the experiment was not explicitly designed to investigate categorical processing of robots and humans and thus the stimulus material did not gradually vary in human-likeness as it did in previous work (Cheetham et al., 2011; Cheetham et al., 2013; Yamada et al., 2013). Consequently, the results give a hint that categorical perception might have taken place, but more investigations are needed to draw concrete conclusions on this topic.

Furthermore, the relationship of human-likeness and the rating dimensions likability and familiarity has been examined. It was found that perceived human-likeness predicted participants' likability and familiarity ratings thereby supporting ***H2***. These results resemble those from Study 3a where human-likeness was also found to be a predictor of likability and familiarity ratings. The relationship between human-likeness and familiarity was particularly strong and human-likeness explained a high percentage of the variance in familiarity scores. This result reflects not only the results of Study 3, but also to some extent participants' answers during the interviews (Study 1) in which some interviewees stated that a human-like appearance is familiar (e.g. "This is more familiar, because at least the head is modeled after a human."). Furthermore, for both relationships (human-likeness & likability; human-likeness & familiarity) it has been examined whether a linear, quadratic, cubic relationship fits the obtained data best (***RQ6***). Altogether, it was found that all three models (linear, quadratic, cubic) are suited to explain the data (for both relationships), but that the cubic models received the best goodness-of-fit and were able to explain more variance than the linear or quadratic models (e.g. 92% variance in familiarity scores). This is surprising, because it contrasts the findings of Study 3a and those of Burleigh et al (2013). However, it has to be acknowledged that the stimulus material in Study 4 differs from Study 3a and from those used in Burleigh et al.'s work in one very important point. It covers the whole range of the robot-human continuum and does not either include different kinds of robots (Study 3a) or human faces (Burleigh et al., 2013), but all these different stimulus categories. Moreover, these studies differ in the measurements used. While in Study 3a aggregated measures have been used (as result of a PCA), in the current study participants rated the stimuli based on single items. This might have contributed to the fact that the models explain higher percentages of variance. However, it is still a fact that the relationships between human-likeness on the one hand and likability and familiarity on the other hand can also be explained by linear models. A visual inspection of the graphs based on the different models (cf. Figure 52 & 53) reveals that the curves are very flattened and do certainly not mirror the exaggerated cubic relationship depicted by *Mori's hypothetical graph* (cf. Figure 5). Taken together, these results illustrate how influential the framing of an experimental set-up is with regard to the occurrence of uncanny valley related effects. The choice of stimuli and measurement can greatly influence uncanny valley related responses. This is, for instance, also exemplified by the relationship of human-likeness and familiarity. When more human stimuli are included, familiarity seems to be closer linked to human-likeness. When the selection of stimuli is restricted to robots, familiarity might be closer connected to the stereotype people have of robots.

In addition, neural correlates of participants' rating behavior have been identified (***RQ1***). While there was no relationship of neural activity and ratings on familiarity, or on likability, results show that activity in the left and right fusiform gyrus was negatively correlated to ratings in human-likeness. Hence, participants rated the stimuli less humanlike when activity in the fusiform gyri was high. Since the included functional localizer could not be used to identify the fusiform face area (FFA), the coordinates of the detected effects were compared with those in previous work in order to identify whether the activation in the fusiform gyrus corresponds to the FFA as found in previous studies. The comparison revealed that the neural activity which was found to be correlated with lower ratings in human-likeness recruits a distinct sub area of the fusiform gyrus which previously has been found to be active when comparing human and robot stimuli (Chaminade et al., 2010; Gobbini et al., 2011). This result will be discussed in more detail in section VI.4.3.

Moreover, it has been examined whether neural correlates could be found for the trial-wise rating differences between two stimuli which were presented together in the decision trials (***RQ2***). No correlations have been found for trial-wise rating differences (delta values) for human-likeness, likability and familiarity.

4.2 Decision behavior, decision uncertainty and relationship of evaluations and decisions

Besides evaluating the stimuli with regard to human-likeness, likability and familiarity participants had to complete a decision-making task. In a decision trial participants were presented with two pictures and they had to choose one of the two presented stimuli with regard to the question from whom they would like to receive a reward. Participants were told that every human or robot presented has chosen one item prior to the experiment that would be given to the participant as reward for their participation. The particular choice of the humans and robots was unknown to the participants. Moreover, there were four items of different hedonic value that the humans and robots would have chosen from (e.g. sparkling wine vs. package of dishwasher tabs), resulting in possibly more or less nice rewards for the participant. Not all stimulus categories were contrasted against each other, but nine planned contrast were chosen to be examined in this paradigm. Healthy humans were contrasted against all other categories and android robots were contrasted against all other categories.

As expected, when given the choice between healthy humans and other stimuli participants strongly tended to choose in favor for the healthy humans in 82% to 95 % of cases (supports ***H3a***). Moreover, they were most confident in their decisions when healthy humans were compared to artificial humans and robots (altogether partial support for ***H3b***). However, they were less confident in their decisions when healthy and disabled humans were compared. Although the decision itself tended to be in favor for the healthy human, it seemed to be a harder decision to decide against the disabled human compared to decide against artificial humans or robots. Since disabled humans were rated as second-best after healthy humans with regard to likability, familiarity and human-likeness, this is not surprising. It could, however, also reflect a mechanism of socially desirable answering, because deciding against the disabled human could be regarded as socially inappropriate and increased decision uncertainty could compensate for this inappropriateness.

With regard to the decisions between android robots and the other categories, participants tended to choose in favor for the healthy and disabled humans, but not in favor for the artificial humans or humanoid and mechanoid robots. Although all effects were significantly different from chance, the decisions between android robots and artificial humans were in particular hard as indicated by their closeness to 50% chance (with 56% in favor for the android robot) and the increased decision uncertainty. As discussed above this might be due to effects of categorical perception.

The relationship of evaluations of the stimuli and participants decisions for or against these stimuli has been examined as well. Results demonstrated that trial-wise rating differences in likability, familiarity and human-likeness between two stimuli predicted participants' choice thereby supporting ***H4a-H4c***. The more participants' evaluation was in favor for the second stimulus (with regard to the three rating dimensions), the more likely participants' chose in favor for the second stimulus.

In addition to the analysis of the behavioral data, it was examined whether there is a relationship between the behavioral data and neural activity. When contrasting rating and decision-making, results showed that different neural activity was observed during the rating task and the decision-making task (***RQ3***). During the rating task neural activity in the fusiform gyrus and the precuneus, both bilaterally, has been found. The area of activation in the fusiform gyrus corresponds to the one found for the negative human-like correlation. Hence, it seems that the fusiform gyrus is strongly involved in the evaluation of the stimuli as human-like and that this activation is genuine to the time of evaluation. Although human-likeness ratings predict the actual choice, there is less activation in the fusiform gyrus when the actual choice takes place. It is, however, an open question whether the activation in the fusiform gyrus during rating directly predicts choices. This question has to be addressed in further analyses. With regard to the activation in the precuneus, the effects found for the right hemisphere resembled the coordinates reported by Krach et al. (2008) and Chaminade et al. (2012). The activation in the left hemisphere, however, seems to be more dorsal than the coordinates found in previous studies. The precuneus has been found to be involved in mentalizing, empathy (social pain and physical pain) or theory of mind tasks (e.g. Cavanna, 2006; Jackson, Brunet, Meltzoff, & Decety, 2006; Lamm, Decety, & Singer, 2011; Masten, Morelli, & Eisenberger, 2011; Schilbach et al., 2006). And also the studies by Krach et al. (2008) and Chaminade et al. (2012) involved tasks requiring mentalizing such as the prisoners' dilemma and rock-paper-scissor playing in cooperation of competition with robots. Hence, it is likely that during evaluation participants thought about the cognitive abilities of the stimuli presented. In contrast to the evaluation, during the decision task there was more neural activity in the right inferior parietal lobule (in the area of the TPJ) and left superior parietal lobule, as well as left superior medial frontal gyrus. Moreover, results showed that confidence ratings were positively correlated with activity in the right subgenual ACC, the left insula, and the inferior parietal lobule (near the temporo-parietal junction) and precuneus, both bilaterally (***RQ4***). Since all these aforementioned brain areas (ACC, precuneus, TPJ, superior frontal gyrus) have been demonstrated to be involved during theory of mind, perspective-taking and empathy tasks (e.g. Jackson et al., 2006; Lamm et al., 2011; Masten et al., 2011; Ruby & Decety, 2004; Schilbach et al., 2006), it is plausible that participants were trying to put themselves into the shoes of the person or robot presented and tried to infer what reward they might have picked in order to come to the decision which stimuli might be the more favorable choice.

This correlation of neural activity at the time of choice and participants' confidence ratings with regard to the TPJ and precuneus was not related to the trial-wise rating differences (with regard to likability, familiarity and human-likeness) although the latter predicted the actual choice on a behavioral level (***RQ5***). However, the lack of a correlation should not be overestimated since this correlation analysis is based on a across-subject analysis which were only 21 data points.

4.3 Explanations: person perception

As discussed in section VI.1.1.1 a number of explanations have been proposed for the uncanny valley effect which are based on nonconformance in perceptual processes such as *conflicting perceptual cues, the violation of previously triggered expectations, errors in the prediction of movement* or *uncertainty at category boundaries.* These explanations share the argument that mismatches in expectations about perceptions and actual perceptions in whatever form cause additional processing on how to interpret, categorize, or react to the stimuli which causes uncertainty and is thus negatively interpreted (e.g. MacDorman et al., 2009). In line with this argument previous work involving robotic and human stimuli demonstrated that additional processing is needed to code a robot face as a face (Chaminade et al., 2010; Cheetham et al., 2011; Dubal et al., 2011; Gobbini et al., 2011). Altogether, robotic faces seem to trigger the common template for faces due to their geometrical characteristics (cf. Kanwisher et al., 1997; Pinker, 1997; Hadjikhani et al., 2009), but increased brain activity is needed in the fusiform face area to decide on whether a real face is perceived or not (***H5***). Indeed, the results of this study provide strong support for this effect.

First, as described above, participants rated the stimuli less humanlike when activity in the fusiform gyri was high. The coordinates for this correlation of human-likeness ratings and brain activity in the medial fusiform gyrus coincide those from previous related work comparing comparison of robotic to human stimuli (Chaminade et al., 2010; Gobbini et al., 2011).

Second, comparisons between the different categories of stimuli during the evaluation of the stimuli support the assumption that robots cause additional processing in the fusiform face area. In partial accordance to the hypotheses, it was found that in comparison to healthy humans, the humanoid and mechanoid robots elicit increased activation in the fusiform gyrus at the same coordinates found for the negative human-like correlation. The android robots, however, did not elicit increased neural activation in comparison to healthy humans. But mechanoid and humanoid robots caused increased activity in the same area in comparison with android robots.

Unexpectedly, disabled humans caused increased neural activity in the fusiform gyrus when compared to healthy humans, but this effect is located in a different area within the fusiform gyrus. The coordinates of this effect correspond more to the activation for solely human stimuli in previous work. This area showed also increased activity for the perception of artificial humans in comparison to android robots.

No differences were found between android robots and disabled humans and between healthy and artificial humans.

Altogether, results suggest that two distinct sub-areas of the fusiform gyrus are responding during the evaluation of human and robotic stimuli. Similar to previous work comparing robots and humans, increased activity in one of these two areas is caused by the perception of robot faces which supposedly trigger the face module but need additional processing to be categorized correctly. A second distinct area which was previously shown to be active solely for human faces shows increased activation for flawed human faces. The stimuli in the group of disabled and artificial humans are definitely human. However, in the group of disabled humans some stimuli possess unusual facial proportions caused by the Down syndrome. In the artificial humans group most faces underwent plastic surgery and possess exaggerated facial proportions (e.g. pumped-up lips, sharp cheek bones, etc.). It seems that those deviations from the face template also cause additional processing, but in a different area than those caused by robotic stimuli.

In this context, it is interesting that android robots did not cause additional processing in either of these regions. The faces of the android robots are to some extent more natural than those of the artificial humans, because they were directly modelled after humans. They differ more with regard to their bodies, which were half-human and half-robot or they looked human, but were presented in kind of a stiff posture. Indeed, android robots (especially Geminoid DK) were often falsely categorized as humans, but far less than the artificial humans which were falsely categorized as robots. Moreover, participants more often decided in favor for the android robots than for the artificial humans. So in conclusion, there seems to be something odd about both stimulus categories. For the artificial humans this seems to be to some extent connected to the facial proportions, while for the android robots not.

4.4 Explanations: social cognition

Previous work has shown that robots can elicit brain activity in social cognition relevant areas. Increasing human-likeness has been found to be associated with increased activation in those areas (cf. Krach et al., 2008). Indeed the results of the present study support the assumption that increased human-likeness is associated with increased activity in ToM relevant brain areas (***H6***). The observed effects follow a similar pattern as the activation patterns regarding face perception. The comparison of healthy humans with humanoid and mechanoid robots resulted in increased neural activity for healthy human stimuli in the precuneus. Moreover, there was also increased activation in the precuneus when comparing android robots with mechanoid robots. While disabled humans elicited more activity in the fusiform gyrus compared to healthy humans, this effect emerged contrariwise for activation in the precuneus and cingulate gyrus which were more activated in the healthy human condition. Similar to the findings concerning face perception, no differences were found when comparing healthy humans and android robots. Furthermore, participants' confidence ratings were positively correlated with activity in the right subgenual ACC, the left insula, and the inferior parietal lobule (near the temporo-parietal junction) and precuneus at the time of choice (***RQ4***). And also the comparison of activity during decision trials and rating trials revealed that during the decision task there was more neural activity in the right inferior parietal lobule (in the area of the TPJ) and left superior parietal lobule, as well as left superior medial frontal gyrus. The activation patters found in the present study partially resemble those found in previous work. For instance, activations in the right precuneus during the rating tasks and the coordinates of the right TPJ activation during decision-making are very similar to those found by Krach et al. (2008) and Chaminade et al. (2012).

All these aforementioned brain areas (ACC, precuneus, TPJ, superior frontal gyrus, etc.) have been demonstrated to be involved during theory of mind, perspective-taking and empathy tasks (e.g. Jackson et al., 2006; Lamm et al., 2011; Masten et al., 2011; Ruby & Decety, 2004; Schilbach et al., 2006). As was discussed above it seems that participants engaged in mentalizing or theory of mind processed to infer what reward the robots and people presented might have picked in order to come to the decision which of the two stimuli might be the more favorable choice.

4.5 Explanations: disgust

Based on the proposed explanation that uncanny valley related responses are based on disgust as evolutionary developed mechanism to *avoid the risk of infection* and the risk of *genetically inadequate mating partners* (cf. MacDorman & Ishiguro, 2006), it was examined whether very human-like robots provide heuristic disease cues and thus elicit responses from the behavioral immune system (Schaller & Park, 2011). In particular, it has been hypothesized that disabled humans, artificial humans and android robots will elicit increased neural activity in the insula during rating trials in comparison to healthy humans (***H7***), but no such effects emerged. However, confidence ratings correlated with activation in the insula at the time of choice. Since the functional localizer for disgust could not be analyzed due to technical problems, there is no reliable way to identify whether the area of activation corresponds to the experience of disgust or other emotions which are also processed. Altogether, there is no strong support for the assumption that uncanny valley reactions are caused by an oversensitivity bias in the behavioral immune system as has been suggested previously (Burleigh et al., 2013; Ho et al., 2008; MacDorman, 2005b; MacDorman & Ishiguro, 2006; Park et al., 2003).

4.6 Implications for the uncanny valley hypothesis

Considering all results from the self-report measures, behavioral data and neuroimaging data there are several important implications for the uncanny valley hypothesis.

Evaluations of humans and robot are indeed driven by perception of human-likeness as indicated by the results of the regression analyses. Furthermore, evaluations of human-likeness strongly depend on the neural processes of face perception. Thus, “smooth” face processing of actual human faces leads to higher ratings of human-likeness and consequently to more positive ratings on other dimensions. In contrast, additional processing caused by incompatible template-activators (robot faces) or flawed human faces is connected to lower ratings in human-likeness and thus a more negative evaluation on other dimensions. However, flawed faces and incompatible template activators caused increased activity in different areas of the fusiform gyrus, although behavioral effects were similar. Human-likeness elicits mentalizing or theory of mind processes. Hence, more human-like stimuli such as healthy, disabled and artificial humans as well as android robots elicited activation in theory of mind associated brain areas. In general, it was observable that participants decided in favor for those stimuli which caused increased activity in the related areas. Moreover, analyses showed that trial-wise differences in human-likeness predicted choices. Altogether, the current work significantly contributed in defining what effect human-likeness has with regard to uncanny valley related reactions on a neural, self-report and behavioral level and how these reactions relate to each other.

Moreover, the present study found strong support for perception-oriented explanations for the uncanny valley effect. First, effects seem to be driven by the aforementioned phenomena in face perception. Further there were indicators for the assumption that categorical perception takes place. However, since the experimental paradigm was not explicitly designed to test for categorical perceptions the conclusions here are preliminary and need further investigation. In the contrary, evolutionary-biological driven explanations assuming that uncanny valley related reactions are due to oversensitivity of the behavioral immune system were not supported by this work.

Regarding the nature of the *Mori's hypothetical graph,* results of the curve fitting analyses indeed showed best goodness-of-fit for cubic models as suggested by the graph. However, the relationships between human-likeness on the one hand and likability and familiarity on the other hand can also be well explained by linear or quadratic models. Moreover, the cubic curves are much flattened and do certainly not mirror the exaggerated cubic relationship depicted by *Mori's graph*. These results illustrate the importance of the experimental set-up and choice of stimuli with regard to the occurrence of uncanny valley related effects.

5. Limitations

There are some limitations to this study. First, the functional localizers for the fusiform face area and disgust related areas failed due to technical problems. Therefore, conclusions with regard to whether the effect found for the insula was disgust related were not possible. Although the areas involved in face-processing matches those found in previous studies, a combination of functional localization and literature based localization is more preferable. Moreover, the experimental paradigm was not suited to explicitly address, for instance, categorical perception, although some of the effects suggest that categorical perception did take place. In future work more gradually varied material on the continuum robot-human could bring more insight into this question. Lastly, the presently reported results are based on whole-brain analyses. Region of interest analyses will be performed in the specified brain regions of interest in future work.

VII. GENERAL DISCUSSION

Since 1970, the uncanny valley has been one of the most popular, highly discussed and referenced theories in the field of robotics (Mori, 1970; Mori et al., 2012). Google delivers 1.6 million hits for the keyword “uncanny valley” (as of 22.11.2013), showing that the hypothesis was and is also of public interest especially with regard to computer animated movies. According to Google Scholar, Mori’s article “the uncanny valley” has been cited 948 times and there are 2830 entries for scientific papers related to the uncanny valley (as of 22.11.2013). The uncanny valley has been discussed and investigated in diverse disciplines such as (social) robotics, design, computer graphics, cognitive psychology, neuropsychology, and sociology. Although the theory was postulated more than 40 years ago, its empirical investigation started just seven years ago. Hence, there remain a number of open questions, some of which have been addressed within this research in the course of four consecutive studies.

First, the goal of this project was to provide a comprehensive review of the concept of the uncanny valley hypothesis, its origin and history, the critique on the hypothesis, proposed explanations for the effect and related empirical work. The major contribution of the literature review is the classification of proposed explanations into three categories: perception-oriented, evolutionary-biological, and cognitive-oriented approaches. All explanations have been theoretically underpinned using relevant theoretical frameworks and empirical evidence from diverse related disciplines. Moreover, the various explanations within one of the three categories have been integrated stressing their commonalities, but also presenting the differences. Based on the literature review, research gaps were identified and a number of research questions was selected which have been addressed in this project.

Essentially, the research centered on the following research objectives:

First, it was important to systematically examine the ***perception of robots with regard to uncanny valley relevant dimensions*** and which design characteristics drive the perception of robots as being, for instance, human-like, likable, familiar or threatening. Moreover, the ***neural correlates*** of the perception and evaluation of robots have been investigated.

Second, the ***significance of Mori’s hypothetical graph*** of the uncanny valley has been called into question. In consequence, how well the obtained data fits to the hypothetical graph was examined. Thus conclusions can be drawn about the actual suitability of the proposed uncanny valley curve.

Third, the project explored the ***influence of participants' age and culture*** as well as the ***social context in which robots are presented*** on the perception of robots.

Fourth, the ***importance of movement*** with regard to the uncanny valley effect has been considered.

Fifth, whether ***uncanny valley effects stem from perceptual or emotional processes*** has been examined. The multi-method approach in this project allowed uncanny valley related effects with ***diverse measurements*** (self-report, behavior, psychophysiology) to be examined and conclusions to be drawn on how these effects are related.

Finally, this work was dedicated to shedding light on the ***significance of the explanatory approaches*** for the uncanny valley effect. Hence, the work focused on the exploratory and systematic investigation of all three categories of explanations: perception-oriented, evolutionary-biological, and cognitive-oriented explanations.

In the following, the four studies, the results and the conclusions will be briefly summarized. Subsequently the results of all four studies will be discussed integrally along the outlined research questions presented above and conclusions with regard to the uncanny valley hypothesis will be drawn.

1. Study 1: Summary and conclusions

The first study utilized qualitative interviews to explore the uncanny valley and possibly related phenomena and aspects mentioned in the literature in more depth. The aim of this initial study was to gain a holistic view of participants' attitudes towards robots in general, and their perceptions and evaluations of different humanoid and android robots in particular. By the choice of stimulus material, interview questions and samples the interviews were suitable for examining the influence of appearance and movement of robots, the influence of context in which human-robot interaction takes place and the influence of age, gender, and culture on participants' attitudes about and perceptions of robots. Moreover, the interview incorporated questions with regard to cognitive-oriented explanations of the uncanny valley, namely uncertainty at category boundaries and subconscious fears of being replaced. The samples were comprised of 16 German and Malayan adults (gender balanced and balanced for participants profession: engineer vs. non-engineer) and 22 German children in two age groups. Interviewees were presented with pictures and videos of three humanoid and three android robots and asked questions with regard to their perception and evaluation of these robots. In addition, general questions were asked for participants' attitudes on diverse robot related topics.

The results of the interviews demonstrated that the robots elicited very diverse reactions. Some were overall perceived very positively, others elicited overall very negative reactions and for some the reactions were rather mixed. Regarding negative reactions participants reported experiencing, for instance, fear, disgust, revulsion, sadness, empathy and pity or, more generally, distress, irritation and confusion. For example, when asked to imagine a rather unusual encounter with a robot (in the cinema) most participants were immediately able to describe their emotional experience and indicate a valence. However, some participants seemed rather detached when looking at the pictures of the robots and stated feeling overall "neutral". Participants' answers to the question regarding how they perceive the robots as well as their answers on concrete scenarios involving robots were greatly influenced by the participants' prior experiences and their initial rather diverse associations. For instance, some participants found the general thought of any robot in a cinema disturbing, whereas others reported sometimes feeling okay with it and sometimes not, depending on whether they liked or disliked the particular robot. The different contexts in the videos influenced participants' perceptions of the robots as well.

With regard to the uncanny valley, it can be concluded that not all android robots per se come together with strongly negative responses, but that the appearance of the particular android played a big role. In general, the appearance of the robots was of great importance, because certain characteristics were equalized with certain abilities. A very human-like appearance was not strongly associated with functionality. On the contrary, the resemblance to humans was perceived as unnecessary and sometimes even inappropriate although outstanding from a perspective of technological achievement. Moreover, participants seemed to apply rules of attractiveness normally used for judging humans to the android robots as well, resulting in positive or negative evaluations based on perceived attractiveness. Since the robots were indeed very different, there were hardly any general tendencies observable for what aspects of appearance were evaluated positively, but participants agreed that a) the robots have to look "finished" and sleek designs were preferred, b) every aspect of appearance of a robot should serve a specific purpose, and c) merely human appearance without a connected functionality is not appreciated. Hence, perceived usefulness also determined a rather positive evaluation of the particular robot and contrariwise apparently useless robots were evaluated negatively. It was interesting that no such close connection could be found regarding familiarity and likability of robots. Likable robots could be both familiar and unfamiliar, as could non-likable robots. Participants' answers revealed that familiarity was conceptualized differently. Robots could be familiar according to the human stereotype or according to the personal stereotype of robots, which also turned out to be very diverse, because stereotypes included industrial robots, functional robots or humanoid robots.

The factor movement was also very influential. High quality of movement in terms of smoothness and adequate velocity was generally evaluated positively. Participants generated expectations about the robots movements. This sometimes resulted in either surprise or disappointment. Disappointments, however, were not always negative, but could also resolve distressing situations. For instance, participants expressed concern that they were not able to tell whether Geminoid HI-1 was a human or a robot. However, they felt relieved that the movement gave its real nature away. This finding contrasts the assumption of the uncanny valley that unrealistic movement in very human-like androids per se causes uncanny valley related reactions.

With regard to the explanations for the uncanny valley it was found that subconscious fears of being replaced (cf. MacDorman, 2005; MacDorman & Ishiguro, 2006, section II.3.3) were not specifically triggered by androids, but were rather generally observable regarding the issue that humans might be replaced by technology in the working context. However, the fears mentioned might be reflected in participants' attitude that robots should not be introduced to those parts of human life and culture where humans try to pursue mastery or virtuosity such as sports, arts and music. On a more concrete level, some participants were very sensitive with regard to the questions of whether they would like to have a doppelgänger. Others were content with a robotic doppelgänger as long as they were in control of it.

With regard to uncertainty at category boundaries, it was found that participants agreed that robots are a kind of machine, but also stated that machines and robot yet possess distinguishing characteristics such as artificial intelligence in robots, multi-purpose usage and often human-like appearance. Robots were distinguished from humans by referring to the life cycle of humans and to more metaphysical or transcendental characteristics such as being self-aware, having a soul, or being creative. In conclusion, a robot was seen as the sum of its parts, but humans were greater than that. However, participants implicitly revealed that there were many overlaps between humans and robots with regard to appearance and certain abilities such as intelligence and autonomy.

Gender and *profession* did not show influences with regard to the perception and evaluation of the robots nor did they influence the answers to the more general questions. However, differences were found with regard to *culture*. German and Malayan participants evaluated the robots partly differently with regard to familiarity and likability. *Age differences* were observed with regard to the question of what distinguishes robots from humans. The children most often referred to physical aspects and mentioned material (metal versus flesh), appearance, quality of movement and speech. In contrast to the adults, the majority of the children liked the idea of having a robotic doppelgänger. Only one third of the children mentioned fears of having to share the attention of friends and parents.

2. Study 2: Summary and conclusions

Since movement was identified as an important factor for the evaluation of robots, the second study examined the influence of varied robotic movement. In a quasi-experimental observational field study people were confronted with the either moving or not moving android robot Geminoid HI-1. The android robot was placed in a public café in Linz, Austria. Since participants were unaware of the nature of the experiment, this offered the chance to explore whether people would recognize the android as a robot and whether this is mediated by different degrees of displayed behavior. Ninety-eight participants were invited to take part in an interview and their interactions with Geminoid HI-1 were analyzed with regard to the following dimensions: the time participants spend in the room with the robot, proximity to the robot, attention paid to the robot, actions to test the robot's capabilities and verbal addressing of the robot.

Results show that two third of the participants identified Geminoid HI-1 as being a robot and one third mistook him for a human (or did not notice anything extraordinary in the café). People encountering a moving android were able to most reliably tell that Geminoid HI-1 was a robot. The effect was fully mediated by the time people spent in the direct area around Geminoid HI-1 (proximity to robot). The robot's movements caused people to spend more time in its adjacency. Hence, they had more time to explore the robot's capabilities and were more likely to identify the robot. This result confirmed the results of Study 1 that the android's behavior serves as a cue to more easily categorize the robot as such. Indeed, participants often referred to the stiff posture and abrupt movements as the reason why they recognized Geminoid HI-1 as a robot. Other reasons were, for instance, the lack of movement, its unexpressive face, clumsy hands or silicone skin.

Moreover, there were differences in participants' behavior between the moving conditions in that movement elicits greater expectations. Participants in the moving condition tested Geminoid HI-1's capabilities by waving their hands in front of its face, saying hello to it, making a grimace or sticking out their tongue in anticipation of an appropriate reaction. Participants encountering the still robot either did not notice it or, if they did, just took a closer look, but did not perform any testing actions. Confirming the results of previous work in observational field studies, huge inter-individual differences with regard to all behavior categories were found (cf. Hayashi et al., 2007; Kanda et al., 2007; Shiomi et al., 2007; Sung et al., 2009; Sung et al., 2010; von der Pütten et al., 2011; Weiss et al., 2010).

With regard to the uncanny valley effect, it was assessed whether people reported unprompted about (negative) feelings regarded as being related to the uncanny valley effect such as distress, fear or disgust. This was not the case except for three participants who stated that the robot gave them an uneasy feeling. However, in contrast to previous work (cf. Becker-Asano et al., 2010), participants were not directly asked about their emotional experience during the encounter with Geminoid HI-1. Thus, no conclusions can be drawn on whether participants did not experience negative feelings, or whether they did, but the negative feelings were only short-term and had already vanished when participants were interviewed. However, with regard to the participants' behavior, results showed that those participants who noticed that Geminoid HI-1 was a robot showed interest rather than negative reactions. There were some statements in the interviews which can be interpreted with regard to Ramey's assumption that robots are at the boundary of categories (e.g. "alive" or "not alive" Ramey, 2006), because participants had difficulties to instantly describe Geminoid HI-1 as either a human being or a robot.

Altogether, the behavioral data showed that although Geminoid HI-1 was deemed to fall into the uncanny valley, people were rather relaxed when meeting it in public in this unscripted situation. For some participants the android robot was not even of particular interest and they were more interested in proceeding with their planned activities.

3. Study 3: Summary and conclusions

In the third study the aspect of robot appearances was examined systematically by means of a web-based survey and an affective priming experiment. The research question was whether certain robot attractiveness indices can be identified and whether these design characteristics influence how people perceive robots. For instance, the uncanny valley hypothesis is based on the assumed relationship between the human-likeness of robots and affinity towards these robots. Since appearance is a very important factor in constituting human-likeness (besides, for example, movement), it is crucial to know what design characteristics are exactly perceived as human-like; or which design characteristics render a robot to be more likable.

The survey contained standardized pictures of 40 different robots including mechanoid, humanoid and android ones of varying size, shape, color, and “gender”. With multivariate analyses, six groups of robots were identified which were significantly rated differently in six dimensions, namely threatening, likable, submissive, unfamiliar, human-like, and mechanical. Based on visual inspections of the derived clusters, possible relationships of design characteristics and the evaluation of robots were outlined.

With regard to human-likeness it was found that android robots were rated as most humanlike, which is not surprising. However, it was surprising that the humanoid robots which had a human-like figure with a torso, head, arms, hands, and legs (Cluster 5) were not perceived as particularly more humanlike than robots which did not necessarily display this human-like figure (e.g. Cluster 1 and 2). Moreover, they were perceived as being most mechanical. This contrasts the commonly accepted assumption that humanoid robots are placed somewhere at the first peak of the uncanny valley (shortly before the downward curve). However, when depicting the robots in the human-likeness dimension (regardless in which cluster they were), it becomes clear that robots with a human-like figure (head, torso, arms, and legs) were still rated more human-like, than those without human-like figures (cf. Figure 38). In addition, it seems that other design characteristics (other than a human-like figure) can also greatly contribute to perceived likability such as the baby-scheme which elicited related ratings (submissive, likable, not threatening, Cluster 1). Upright walking and height seemed to contribute to a negative perception of a robot as being dangerous which also reflected the concerns expressed by some interviewees in the first study - that such a robot could “come after” them.

Participants obviously understood familiarity in terms of *familiar according to the human stereotype*. Human-likeness served as predictor for familiarity ratings. Hence, the most unfamiliar robots were those with rather futuristic shapes (Cluster 6).

Regarding likability, it was found that the android robots and the robots with a baby-scheme were rated as most likable. Moreover, human-likeness and mechanical ratings predicted likability scores so that more human-like and less mechanical robots, respectively, were perceived to be more likable. The android clusters differed in their likability ratings. Participants' additional written statements about the robots suggest that the androids displaying gender, race, and culture might have caused in- or out-group biases in likability ratings. But given that the sample included only four android robots this conclusion remains speculative and would need further investigation.

Moreover, whether evaluations of actual robots can be explained by a cubic function as suggested by the uncanny valley theory was examined. Base on previous work (Burleigh et al., 2013; Ho & MacDorman, 2010) *likable* and *threatening* ratings were considered for analysis as well as *human-likeness* and *mechanicalness* ratings. Results showed that, the data in this study could not be explained by a cubic function as would be suggested by the uncanny valley graph proposed by Mori, but rather by linear relationships. It was found that increased human-likeness resulted in higher likability and lower threatening ratings and increased mechanicalness resulted in lower likability ratings. Only the relationship between mechanicalness and *threatening* was clearly not linear but quadratic. Hence, very mechanical and least mechanical robots (android robots) are perceived as most threatening, while medium mechanical robots are least threatening. This finding implies that *likable* and *threatening* might indeed be two distinct dimensions instead of the extremes of one dimension as proposed by Ho and MacDorman (2010). Therefore, Mori's hypothetical graph would be misleading, because it would integrate participants' responses on two dependent variables into one dependent variable, thereby distorting the real relationship between human-likeness and affinity or eeriness, respectively.

In the second part of the study, a smaller sample of robots representing the clusters were included in a laboratory experiment using affective priming in order to confirm the findings from the survey with an implicit measure. Results showed that participants revealed neither particularly strong positive nor strong negative implicit attitudes towards the robots presented. Moreover, there was no correlation between explicit evaluation of robots and implicit attitudes towards robots. It seems that the strength of the object-evaluation association which "determines the accessibility of the attitude from memory and, hence, the likelihood that the associated evaluation will be activated automatically upon the individual's exposure to the attitude object." (Fazio, 2001, p. 122) is not very strong for robots. Since robots are not everyday objects, it could be that they are rather "weak primes" with a low likelihood of eliciting associated evaluations.

4. Study 4: Summary and conclusions

The aim of the last study, an fMRI study, was to test explanatory approaches for the uncanny valley. Based on the stimulus material from Study 3, android robots, humanoid robots and mechanoid robots were included. Moreover, three additional stimulus categories included human stimuli, namely healthy humans, disabled humans, and artificial humans (photomontage of humans). An experimental paradigm has been developed which allowed the examination of participants' evaluations of these humans and robots with regard to uncanny valley relevant rating dimensions (likability, familiarity, human-likeness) and behavioral measures (decide between two of the stimuli) combining these measures with measured brain activity. It was analyzed whether there are uncanny valley related effects in behavior and evaluations and whether these can be explained by the proposed explanations for the uncanny valley. More specifically, it was examined whether uncanny valley related effects occur due to a) additional processing during face perception of human and robotic stimuli, b) automatically elicited processes of social cognition, or c) oversensitivity of the behavioral immune system.

As expected, results showed that the healthy humans were perceived to be most humanlike, followed by disabled humans, android robots and artificial humans, humanoid robots and mechanoid robots. A higher perceived human-likeness led to higher likability and familiarity. In contrast to the results of Study 3, this relationship could be explained by linear, quadratic and cubic relationships, among which the cubic models received the best goodness-of-fit and were able to explain more variance than the linear or quadratic models. Study 4 differs in one important point from Study 3 and Burleigh et al's (2013) experimental paradigm: it covers the whole range of the robot-human continuum and does not either include different kinds of robots (Study 3a) or human faces (Burleigh et al., 2013) which might be an explanation for the good fit of the cubic model. However, a visual inspection of the three model curves revealed that the curves were very flattened and do certainly not mirror the exaggerated cubic relationship depicted by *Mori's hypothetical graph*.

With regard to the decision making, participants strongly tended to choose in favor of the healthy humans when given the choice between healthy humans and other human or robotic stimuli and they were very confident in this decision. The only exception were decisions between healthy and disabled humans, where participants were less confident, probably due to a social desirability bias. Participants decided in favor of the android robots when these were compared with artificial humans or humanoid and mechanoid robots, but not when they were compared with healthy or disabled humans. In addition, it was found that participants' evaluations of the stimuli predicted their choice: the more participants' evaluation during the rating trials was in favor of the second stimulus in a decision trial, the more likely participants' favored the second stimulus.

Regarding the proposed *explanations*, it was found that evaluations of humans and robot with regard to human-likeness strongly depended on the neural processes of *face perception*. It seems that additional processing in the fusiform face area caused by incompatible face-template activators (robot faces) or flawed human faces (e.g. disabled humans, artificial humans) is connected to lower ratings in human-likeness and thus a more negative evaluation of other dimensions. However, flawed faces and incompatible face-template activators caused increased activity in different areas of the fusiform gyrus, although behavioral effects were similar.

Moreover, results suggest that effects during evaluation are related not only to processes of face perception, but that *social cognition processes* took place (e.g. thinking about cognitive abilities of stimulus) as indicated by activation in the precuneus which mirrors prior findings (cf. Chaminade et al., 2012; Krach et al., 2008). Regarding the decision-making task, correlations were found with activity in brain areas associated with decision making such as subgenual ACC and insula (cf. previous work, e.g. Rolls et al., 2010) and those associated with theory of mind and mentalizing such as inferior parietal lobule (near the TPJ) and precuneus (cf. previous work, e.g. Jackson et al., 2006; Lamm et al., 2011; Masten et al., 2011; Ruby & Decety, 2004; Schilbach et al., 2006). Hence, it seems that participants were trying to put themselves into the shoes of the person or robot presented and tried to infer what reward they might have picked in order to come to the decision which stimuli might be the more favorable choice.

Interestingly, no effects emerged supporting the assumption that uncanny valley reactions are caused by an *oversensitivity bias in the behavioral immune system* (cf. Schaller & Park, 2011) as has been suggested by diverse scholars examining the uncanny valley hypothesis (Burleigh et al., 2013; Ho et al., 2008; MacDorman, 2005b; MacDorman & Ishiguro, 2006; Park et al., 2003).

One interesting effect emerged: it seems that for the given data android robots and artificial humans mark the *category boundary* between humans and robots. They did not differ in regard to perceived human-likeness. Although participants decided in favor of the android robots, this effect was not as clear as the other effects. Moreover, participants reported the lowest decision confidence and they showed least accuracy in their categorizations of artificial humans and android robots as either human or robot in the post-questionnaire. These findings are in accordance with indices found in previous studies examining category boundaries (Cheetham et al., 2011; Cheetham et al., 2013; Yamada et al., 2013). Hence, it could be the case that the stimulus material underwent categorical perception (cf. Harnad, 1990). However, more research would be needed, because the experiment was not explicitly designed to investigate the categorical processing of robots and humans, and thus the stimulus material did not gradually vary in human-likeness as it did in previous work (Cheetham et al., 2011; Cheetham et al., 2013; Yamada et al., 2013).

5. Conclusions with regard to research objectives

5.1 Perception of robots & significance of the uncanny valley graph

One research objective of this project was to examine what aspects determine the ***perception of robots with regard to uncanny valley relevant dimensions***. In this regard, three of the four studies asked for participants' perceptions of robots (and humans, respectively, in Study 4). In Study 1 participants had the chance to elaborate on their perceptions of six particular humanoid and android robots. Although the interviews were partly structured, there was enough opportunity for the participants to think about possible reasons for their perceptions. Hence, the interviews provided individual in-depth information with regard to the perception of a limited set of robots. A more systematic approach was applied in the Studies 3 and 4 which were based on standardized material of a larger set of actual existing robots. It was examined which design characteristics drive the perception of robots as being, for instance, human-like, likable, familiar or threatening (Study 3). Moreover, the ***neural correlates*** of the perception and evaluation of robots have been investigated (Study 4).

With regard to the uncanny valley the perception of an object as *being human-like* is of great importance. Within the uncanny valley hypothesis and especially in Mori's hypothetical graph the x-axis is the dimension of human-likeness (Mori, 1970), but what constitutes human-likeness is not clearly defined. However, two important factors which are also core factors of the uncanny valley hypothesis are appearance and movement. Appearance is the factor which has been addressed most frequently in studies investigating the uncanny valley (Bartneck et al., 2007; Burleigh et al., 2013; Cheetham et al., 2013; Cheetham et al., 2011; Hanson et al., 2005; Hanson, 2006; Lay, 2006; MacDorman & Ishiguro, 2006; Riek et al., 2009; Saygin et al., 2012; Seyama & Nagayama, 2007; Tinwell & Grimshaw, 2009), followed by the factor movement (Bartneck et al., 2009; Minato et al., 2004; Minato et al., 2006; 2006; Shimada et al., 2006; Shimada & Ishiguro, 2008; Thompson et al., 2011). Indeed, also the present work demonstrated the importance of appearance with regard to human-likeness. The results of the different studies paint a rather complex picture.

As can be intuitively expected, android robots were perceived to be very human-like in all studies which is certainly due to the fact that their outer appearance closely resembles that of humans in all possible dimensions. However, also single aspects of the human form can influence perceived human-likeness, for instance, the existence of a human-like figure or facial features in an otherwise clearly mechanical object. These effects seem to be aggravated if the specific aspect of human-like appearance exposes a form that evokes positive associations. An example for this effect would be that facial features contribute to perceived human-likeness and that this effect is reinforced for facial features that are designed according to the baby-scheme (cf. Hückstedt, 1965; Glocker et al., 2009) as can be concluded from the evaluations of Cluster 1 und Study 3.

When the robots in Study 3 were depicted along the human-likeness dimension, it became clear that robots with a human-like figure (head, torso, arms, and legs) were rated more human-like, than those without human-like figures. Moreover, robots at all stages of the human-likeness dimension exhibited facial features, and thus suggest that the existence of facial features did not particularly contribute to perceived human-likeness. This stands in contrast to prior work by DiSalvo et al. (2002) and Powers et al. (2006) who examined the influence of facial features on perception of robots and showed that not only the existence of facial features contributes to human-likeness, but that also the proportions of facial features are influential. However, the studies by DiSalvo et al. and Powers et al. only included robot heads and neglected the influence of robotic bodies on perceptions of human-likeness. The results of Study 4 also suggest that facial features are important, as their existence elicits automatic face processing as indicated by the increased activity in the fusiform gyrus. Admittedly, the fusiform gyrus was shown to be responsive to faces and bodies in the so-called fusiform face area (FFA) and fusiform body area (FBA) which are adjacent, but distinct areas (Schwarzlose, Baker, & Kanwisher, 2005). Since the functional localizer for the FFA failed, the conclusions with regard to face processing are based on the very similar coordinates found in previous work using robotic faces (Chaminade et al., 2010; Gobbini et al., 2011). However, the possibility that not only the FFA but also the FBA was activated cannot be excluded. Altogether, the behavioral results suggest greater importance of robotic bodies than of robotic faces and the results of the functional imaging data suggest greater importance of faces, but have to be interpreted with care. Thus, no final conclusion can be drawn on whether one of these aspects of appearance is more influential. This is also supported by participants' statements in the interviews. The robots' faces were certainly important with regard to participants' evaluations of these robots, but participants also often referred to the human-like figure as defining human-likeness.

Furthermore, there seems to be a complex interplay of different aspects of appearance. For instance, the humanoid robots in Study 3 were not rated as particularly likable. A possible explanation would be that the positive effect of a human-like figure has been undermined by the overall more bold and bulky appearance. On the other hand, participants did not appreciate a mere human form without functionality, as was the case for CB2 and Geminoid HI-1 in Study 1.

Altogether, it seems that at least on the individual level in the interviews increased human-likeness is not per se accompanied by positive evaluations. This is also supported by the observation that a human-like figure was often associated with having certain abilities and having these abilities was on the one hand positively evaluated (e.g. robot is capable and thus can help), but on the other negatively interpreted (e.g. robot is capable and thus a threat). Moreover, in the interviews human-likeness was not particularly connected to familiarity. Participants' stereotype of a robot varied greatly from functional to humanoid robots. Therefore, participants applied different criteria for judging familiarity – sometimes they understood familiarity in terms of *familiar according to the human stereotype* and sometimes as *familiar according to the robot stereotype.* Contrariwise, the questionnaire data from Study 3 and 4 demonstrated positive relationships between human-likeness on the one hand and likability and familiarity on the other. More human-like robots were also more likable and familiar. Here, participants obviously understood familiarity in terms of *familiar according to the human stereotype*. Taken together, these results bolster the critique that familiarity should be used with care when investigating the uncanny valley, because a) it is not the adequate concept to mirror Mori's term "shinwa-kan" which is best translated as affinity or likability, and b) it is difficult to use familiarity due to its ambiguousness (cf. Bartneck et al., 2007; Bartneck et al., 2009). With regard to likability, it seems that again on the individual level in the interviews mere human-like appearance does not necessarily determine likability. Participants' statements in the interviews (Study 1) revealed that Geminoid HI-1 was often negatively perceived because of its stern facial expression, whereas HRP-4c was often perceived as likable because of its obvious female gender. Hence, likability depends also on other criteria (at least for android robots) such as perceived gender, race, culture, which are all factors that can cause in- or out-group biases in likability ratings (cf. Eyssel & Hegel, 2012; Eyssel & Kuchenbrandt, 2012). Moreover, facial expressions seem to be influential for the evaluations of robots, just as they are for the evaluations of humans (cf. Lau, 1982). Moreover, with regard to the non-android robots facial features according to the baby-scheme seem to have a positive effect on likable ratings, although statements in the interviews were quite mixed with regard to this topic. However, despite these results that show how differently aspects of human-like appearance might be evaluated by individuals, this work also demonstrated the general trend that perceived human-likeness of robots predicts perceptions of robots as being likable, threatening, and familiar. These observations will be discussed below (*significance of Mori's hypothetical graph*).

Another significant finding is, that in Study 4 only ratings of human-likeness were correlated with neural activity and not ratings of likability or familiarity (cf. Figure 54). Participants rated the stimuli less humanlike when activity in the fusiform gyri was high, thereby confirming the assumption that additional processing during face-perception is related to the uncanny valley effect (cf. Chaminade et al., 2010; Cheetham et al., 2011; Dubal et al., 2011; Gobbini et al., 2011; MacDorman et al., 2009). These results demonstrate the importance of the factor human-likeness and justify the attention it received in previous studies. The subsequent evaluations of humans and robot were then driven by the perception of human-likeness as was demonstrated by the regression analyses. In turn all three aspects of evaluation (human-like, likable, familiar) predicted participants' behavior in terms for deciding for or against a stimulus. Moreover, decision behavior was correlated directly to neural activity in brain areas which were shown to be involved in decision making, especially with regard to the pleasantness of stimuli (subgenual ACC, Rolls et al., 2010) and were correlated with brain areas which are also involved in theory of mind tasks (precuneus, TPJ, Cavanna, 2006; Saxe & Kanwisher, 2003; Saxe & Wexler, 2005). These results show direct relations of patterns of neural activity with rating behavior and decision behavior, but also indicate an indirect influence of neural activity during ratings on behavioral effects in decision making (cf. Figure 57). However, more analyses with regard to this connectivity including structural equation modelling or path analysis of fMRI data would be needed to investigate this assumed indirect effect.

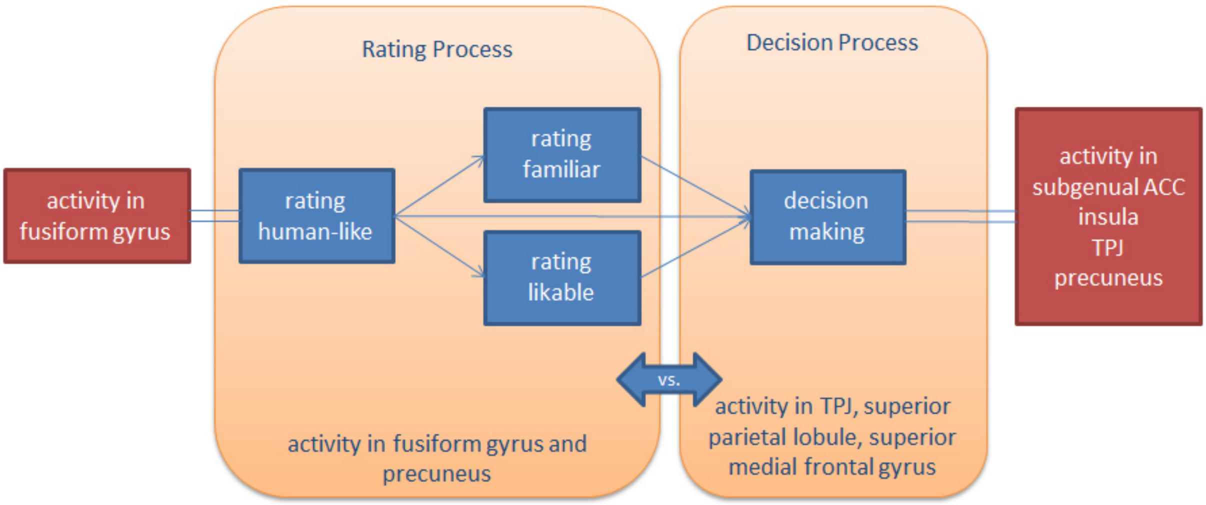


Figure 57: Schematic depiction of relationships between neural activity and behavioral measures

Besides exploring what determines the perception of robots as being human-like, familiar and likable, the ***significance of Mori's hypothetical graph*** of the uncanny valley has been called into question. The uncanny valley theory predicts a nonlinear relationship between human-likeness and some uncanny valley related response on the part of the user (most often ratings on familiarity or likability; Mori, 1970; Mori et al., 2012). Examining Mori's graph the depicted curve can best be described by a cubic function. Hence, it was examined how well the obtained evaluation and rating data of Study 3 and 4 fit to Mori's hypothetical graph. In contrast to previous attempts at reproducing the uncanny valley curve (e.g., Burleigh et al., 2013; Cheetham et al., 2013; Cheetham et al., 2011; Green et al., 2008; Hanson, 2006; Hanson et al., 2005; Lay, 2006; MacDorman, 2006; MacDorman & Ishiguro, 2006; MacDorman et al., 2009; Seyama & Nagayama, 2007, 2009; Tinwell & Grimshaw, 2009) standardized pictures of actual existing robots were used in Study 3. The stimulus material of Study 4 was based on a selection of robots from Study 3 and eighteen standardized pictures of humans were added. Hence, the studies differ with regard to the included range of stimuli on the dimension of human-likeness. While Study 4 theoretically covers almost the whole dimension of human-likeness (from mechanoid robot to healthy human), Study 3 covers only a part of the dimension (from mechanoid robot to android robot). In Study 3 human-likeness and mechanicalness were used to predict ratings on how likable and threatening the robots were perceived to be. In Study 4 human-likeness on the one hand and likability and familiarity on the other were put into relation. In both studies, results demonstrated that human-likeness (and in study 3 also mechanicalness) predicted ratings with regard to likability and familiarity and in Study 3 also with regard to threatening. Moreover, in both studies data were explained well by linear models. However, the examination of alternative models, quadratic and cubic models, and their comparison with the linear models revealed differences between the two studies. For this purpose all three models were calculated and the goodness of fit was assessed and compared for the three.

In Study 3, results suggested a linear relationship between *human-likeness* and *threatening* and a linear or quadratic relationship between *human-likeness* and *likable*. Furthermore, results suggested a linear relationship for *mechanicalness* and *likable*. Only the relationship between *mechanicalness* and *threatening* was clearly not linear but quadratic. In all cases cubic relationships were least suitable to explain the data. In Study 4, it was found that all three models (linear, quadratic, cubic) were suited to explain the relationships between human-likeness and likability and familiarity, but that the cubic models received the best goodness-of-fit. The results of Study 4 were surprising, because they contrast with those from Study 3 and those of Burleigh et al (2013). However, as mentioned above the studies differed with regard to the stimulus material. Study 4 covered the whole range of the robot-human continuum and neither included different kinds of robots (Study 3) nor human faces (Burleigh et al., 2013). The studies also used different measurements (single items versus aggregated measures).

Altogether, the proposed relationship between human-likeness and affinity indeed exists. Its form, however, varies in dependence on the stimulus material and the measures used. In addition, a visual inspection of the graphs based on the different models as well as the graphs from previous related work (cf. section II.4.1 for examples) revealed that the curves are usually very flattened and do not mirror the exaggerated cubic relationship depicted by *Mori's hypothetical graph* (cf. Figure 5). Moreover, the present data showed that all relationships can also be explained by linear models. These results illustrate how influential the framing of an experimental set-up is with regard to the occurrence of uncanny valley related effects. The choice of stimuli and measurement can greatly influence uncanny valley related responses. This is, for instance, also exemplified by the relationship of human-likeness and familiarity. When more human stimuli are included, familiarity seems to be more closely linked to human-likeness. When the selection of stimuli is restricted to robots, familiarity might be more closely connected to the stereotype people have of robots.

In conclusion, there is some weak evidence for the significance of Mori's graph. It is, however, more likely that the uncanny valley relevant dimensions are subject to linear relationships in the sense of what is more human-like is also more likable and more familiar.

These results are limited to still pictures. Other relationships might emerge, for instance, for videos when other factors of human-likeness are included and not only appearance.

5.2 Influence of age, culture and personality traits on uncanny valley related responses

In this project it was also explored how ***participants' age and culture*** as well as the ***social context in which robots are presented*** influence the perception of robots. It has been proposed that uncanny valley related responses could be culturally dependent (cf. Brenton et al., 2005; Gee et al., 2005). For instance, Gee et al. assume that culture may affect people's responses to robots, depending on how robots are presented in the media in their particular culture. The authors exemplify that in Japan robots are generally presented as "good", whereas robots in western cultures are generally presented as "bad" entities and this would result in a more general positive attitude towards robots in the Japanese culture. Moreover, it has been discussed that the world religions also differ in aspects relevant to the uncanny valley. For instance, Buddhism and Shintoism attribute spirits to things and not uniquely to humans (for a discussion also see Mori, 1981), while in Christianity the human was created in the likeness of God and thus it is impudent to appoint oneself as creator by building android robots. In addition, it has been proposed that participants' age has an influence on their perception and evaluation of robots.

Thus, the effects of age and culture were explored in the qualitative interviews, where samples were chosen accordingly. The interviews included a sample consisting of German and Malayan adults balanced for gender and for their profession (engineers, non-engineers) and a sample of children aged from five to eleven. Participants' interview answers were analyzed with regard to influences of culture, gender, profession and age. Results revealed no influence of *gender* and *profession* with regard to the perception and evaluation of the robots, but there were differences with regard to *culture.* These were limited to certain aspects of the interview, but interestingly, they are tangent to the uncanny valley related concepts of *familiarity* and *likability*. German and Malayan participants differed in their statements about how familiar or likable the particular robots were. For instance, Germans tended to like HRP-4c and CB2 less and to like Geminoid HI-1 more than Malayans. Further, *age differences* were found. The children obviously had other concepts about what defines a robot and what defines a human. When distinguishing robots from humans, the children's answers were less varied than those of the adults, their statements concentrated more on physical aspects (material (metal versus flesh), appearance, quality of movement and speech) rather than on metaphysical concepts such as being self-aware, or having a soul. The adults' concept of humans is more comprehensive than that of the children, including more aspects of humanness and uniquely human abilities that are intangible and elusive. In consequence, the concepts of humans and robots showed more overlaps in the children's' answers which might be the reason why they were more open to the idea of meeting or owning a robot, even if it was a robotic doppelgänger of themselves.

Besides the factors age, profession and culture, personality traits were also examined in this work. In Study 3, results showed that participants with higher scores in Robot Anxiety overall evaluated the robots as more threatening. Men evaluated the robots as more submissive than women and extraverted people also judged the robots as being more submissive. Altogether, there were some limited influences of gender, personality and robot anxiety on the evaluation of robots in Study 3. However, the effects explained only small degrees of variance and thus have to be interpreted with care. More systematic research would be needed to explore the influence of participants' personality traits on the perception of robots in more depth.

5.3 The influence of movement on uncanny valley related reactions

Mori's uncanny valley hypothesis described that the unnerving uncanny valley effect would be more pronounced in moving than in still objects. It is difficult to say clearly how Mori thought to integrate movement into his hypothesis, because the x-axis merely refers to human-likeness. Movement seemed to be a moderating variable that reinforces the effect of human-likeness on affinity. Bartneck et al. (2009) also emphasized that Mori's hypothesis of the uncanny valley is too simplistic on this point and that human-likeness or anthropomorphism would not only be conditioned by mere appearance, but also by behavior, because movement contains social meanings and, thus, may have direct influence on the likability of a robot. Hence, the importance of movement in the hypothesis is not clear. This might be a reason for why behavior was less often addressed than appearance in experimental uncanny valley related research. Research concentrating on the factor movement often utilized android robots (Bartneck et al., 2009; Minato et al., 2004; Minato et al., 2006; Shimada et al., 2006; Shimada & Ishiguro, 2008; Thompson et al., 2011) and did not compare different kinds of robots. Moreover, the context in which the robots were presented was neglected. Therefore, the present work also addressed how movement influences participants' perception of robots. On the one hand, this was achieved by exploratory analyses based on very diverse material in the qualitative interviews (Study 1). On the other hand data from a more controlled field experiment was analyzed with regard to the influence of an android's movement (still vs.

moving) on participants' perception of the android and their behavior towards the android (Study 2).

The interview results demonstrated that *movement* was a highly influential factor. First, participants evaluated rich motion behavior, high smoothness of movement and adequate velocity as positive. In contrast, limited movement was either seen as appropriate for less human-like robots or as disappointing. Participants had quite high expectations about how robots should move, probably induced by examples of robots in movies. Expectations were greater for more human-like robots. Moreover, participants generated expectations about the robots movements from the pictures they saw earlier in the interviews. When their expectations were not met in the videos, they reacted with either surprise or disappointment. Unlike to the statements regarding the robots' appearance, there were no hints that the movement of a robot itself was perceived as eerie or uncanny. In contrast, it sometimes made a robot more predictable as was the case with Geminoid HI-1 in the interviews. Although the majority of the participants reacted with distress when they learned that the Asian man in the picture was a robot, some of them were quite relieved on seeing Geminoid HI-1's limited movements. The movement provided the necessary cue to clearly categorize Geminoid HI-1 as a robot. This reflects how complex the interplay of appearance and movement is. Unlike the general assumption of the uncanny valley hypothesis that unrealistic movement in very human-like androids causes negative reactions, it seems more likely that realistic movements would cause these reactions, because they exacerbate discrimination processes. In addition, the robots and also the displayed movement, were evaluated with regard to the context the robots were presented in. For instance, limited and slow movement was okay for the AR robot, because they seemed sufficient for the function the robot should fulfill. The movement of CB2 was regarded as very lifelike, but participants did not see a particular use for the robot and its realistic childlike movements. This contributed to a more negative evaluation of the robot.

In Study 2, the behavior of the android robot was varied. Geminoid HI-1 was either sitting relatively still in front of a laptop, or he was just sitting there but established eye contact with passersby. Similar to the interview results, it seems that the android's movement provided the necessary cue to recognize him as a robot as indicated by participants' statements in the interviews after the interaction. When participants encountered the still robot, they referred to the stiff posture or the lack of movement as reasons for why they recognized it as a robot. But more interesting is the fact that the moving android was of greater interest to the participants.

Only in the moving condition, participants tested Geminoid HI-1's capabilities by waving their hands in front of its face, saying hello to it, making a grimace or sticking out their tongues in anticipation of an appropriate reaction. It seems that the robots behavior invites people to follow their curiosity and explore the robot. It can be concluded that the android's movement did not necessarily lead to negative reactions. At least most participants did not report any negative experiences.

With regard to the uncanny valley, more systematic research, for instance with gradually varied behavior, is needed to examine the role of movement not only with regard to android robots, but also regarding humanoid and mechanoid robots.

5.4 The uncanny valley as emotional reaction

Reading the literature carefully, it becomes clear that it is often assumed implicitly that the ***uncanny valley is a negative emotional reaction***. It is, however, unclear what exactly an uncanny valley related reaction is, because this was not defined in Mori's hypothesis which refers only to "affinity" or "eeriness". These concepts can be operationalized differently. Hence a variety of different measures (self-reporting, behavior, psychophysiology) have been used to explore the phenomenon in previous work, but not all were adequate for drawing conclusions on whether the observed reactions were emotional. This research project, thus tried to combine measures with the aim of providing deeper insights into the nature of these reactions.

First, participants were directly asked to indicate whether they experienced emotional states or not when looking at pictures or watching movies of robots (Study 1). Then it was examined whether people report unrequested about negative experiences when encountering an android robot (Study 2). Moreover, it was investigated whether brain regions responsible for emotion processing are relevantly involved during the perception of humanoid and android robots (Study 4).

In the interviews, participants reported varying reactions towards the different robots. While some experienced positive or negative emotions, others seemed to be rather detached and reported feeling overall "neutral". When participants reported negative emotions they included very different emotional states such as fear, disgust, revulsion, sadness, empathy and pity which also imply different underlying meanings, because a reaction based on fear is different from a reaction based on pity. However, participants' answers were influenced by the nature of the interview questions. General questions asking for participants' reactions when looking at a picture elicited less emotional responses than questions where participants are asked to imagine a possibly stressful situation with a robot. And as already mentioned, the experience of emotional states seemed to be individually different.

In Study 2 participants answers in the post-interaction interviews were analyzed with regard to whether they reported unprompted (negative) feelings during or after the encounter with Geminoid HI-1. Only three people (4%) mentioned that Geminoid HI-1 gave them an uneasy feeling. In contrast to Study 1 and also in contrast to previous studies (e.g. Becker-Asano et al., 2010), participants were not explicitly asked for their feelings. Thus, they might have held back with this information, because they did not regard this as important or appropriate to be mentioned during the interview. However, it could be also the case that the majority of the participants either did not experience negative feelings, or that these feelings had already vanished or had been resolved during and after the interaction with the robot. In conclusion, participants seemed to be rather relaxed and more interested in meeting a robot in a public space.

In Study 4 it has been examined whether brain regions responsible for emotion processing are relevantly involved during the perception and evaluation of very human-like robots. The results showed that during the evaluation of robots only face-responsive brain areas (FFA) were correlated to the actual rating behavior. With regard to the decision behavior there was a correlation with neural activity in the insula which has been associated with the experience of both positive and negative emotional states such as romantic love, fear, disgust, pain (cf. Bartels & Zeki, 2000; Calder et al., 2007; Chapman & Anderson, 2012; Danziger, Faillenot, & Peyron, 2009; Singer, Critchley, & Preuschoff, 2009), but admittedly the insula fulfils a variety of different functions and thus no clear conclusions can be drawn without further systematic research in this regard.

Altogether, it seems that some participants experience emotional states, at least when possibly distressing situations are induced by imagination. These reactions are, however, not necessarily negative. Moreover, the situational context seems to play a role. For instance, volunteers who know that they are taking part in an experiment might be more nervous than people who are participating unknowingly in an experiment. Looking at pictures and videos might be more or less distressing than encountering a robot. From the current data it seems that participants who imagined situations with a robot were more distressed than people actually meeting a robot in public. Moreover, it cannot be ruled out that participants in the interviews, on the basis of the interview questions, thought that the interviewer wanted them to report emotional states and answered accordingly to fulfill the aim of the experiment. Thus, future studies might also include other more objective measures such as psychophysiology (skin conductance, heart rate) to identify distressing situations during interviews or interactions. In this regard, current work in the field of human-robot interaction is very promising (Rosenthal-von der Pütten et al., 2013; Castellano et al., 2013), especially because new portable devices are on the market which can be used during interaction without restricting the participants' mobility (Leite, Henriques, Martinho, & Paiva, 2013). Moreover, studies utilizing fMRI could be used to explore the emotional responses to robots in more depth (cf. Rosenthal-von der Pütten et al., 2013).

5.5 Explanatory power of proposed explanations

Finally, this work was dedicated to shedding light on the ***significance of the proposed explanatory approaches*** for the uncanny valley effect. In section II.3 the proposed explanations were summarized and categorized into three categories of explanations: perception-oriented, evolutionary-biological, and cognitive-oriented explanations. Perception-oriented explanations for the uncanny valley effect include *conflicting perceptual cues, the violation of previously triggered expectations, errors in the prediction of movement* or *uncertainty at category boundaries* (cf. Bartneck et al., 2007; Burleigh et al., 2013; Cheetham et al., 2013; Cheetham et al., 2011; MacDorman & Ishiguro, 2006; MacDorman et al., 2009; Saygin et al., 2012). Evolutionary-biological explanations are based on the assumption that uncanny valley reactions are reactions due to an oversensitivity bias of the behavioral immune system (cf. MacDorman & Ishiguro, 2006; Park et al., 2003; Park et al., 2007; Rozin & Fallon, 1987; Rozin et al., 1999; Schaller & Park, 2011). These reactions might cause increased mortality salience which has also been proposed as an explanation for the uncanny valley effect (MacDorman & Ishiguro, 2006). Finally, cognitive-oriented explanations include *sorites paradoxes involving personal and human identity, categorical perception, and subconscious fears of reduction, replacement, and annihilation* (cf. MacDorman & Ishiguro, 2006; Ramey, 2005, 2006).

In this work some of the above presented explanations were tested for their explanatory power. In Study 1, cognitive-oriented explanations were addressed during the qualitative interviews, for instance, by asking participants about fears related to human-like robots or about how they categorize robots and humans. Evolutionary-biological explanations were in the focus of Study 4, which examined whether uncanny valley related reactions were induced by disgust. Further, the fourth experiment investigated how humans and robots were perceived not only based on self-report, but also based on the neural activation during evaluation of stimuli and decision-making about these stimuli and thus enabled an examination of perception-oriented explanations.

With regard to *cognitive-oriented explanations*, the results of Study 1 revealed that some participants indeed mentioned fears of being replaced (cf. MacDorman, 2005; MacDorman & Ishiguro, 2006), although not all the participants gave related statements. Participants stated that they would not like to see robots take over the jobs of humans unless humans were given more preferable jobs. In addition, they said that some activities should be exclusive for humans, because these are opportunities for virtuosity. Thess included sports, arts and music. Interviewees' answers on the question of robotic doppelgangers were more directly connected to the fear of being replaced. While some participants were quite relaxed about this question, others expressed concerns that robots might live among humans unrecognized, or that they would have to share the attention and love of others with a personal robotic doppelgänger. Furthermore, interview questions addressed the topic of whether robots are at category boundaries and thereby eliciting states of uncertainty (cf. Ramey, 2006; section II.3.3). It was found that indeed participants' concepts of humans and robots showed some overlaps, for instance, with regard to certain abilities (human-like appearance, being able to fulfill a variety of tasks, ability to move, (artificial) intelligence, etc.). However, participants also found distinguishing aspects and referred to the life cycle of humans and more metaphysical or transcendental characteristics such as being self-aware, having a soul or being creative. Hence, participants revealed that there were many overlaps between humans and robots with regard to appearance and certain abilities. Also the interviews in Study 2 showed that participants had initially problems in categorizing Geminoid HI-1 as human or robot. Some participants indeed did not instantly describe Geminoid HI-1 as either a human being or a robot, but described their confused first impressions as, for instance, "kind of artificial being" or "extraterrestrial". Others described the robot with terms like "disabled person" or "weird person" indicating that they predominantly had the impression of a human being, but recognized something that did not fit into the stereotype of a healthy man. Some results of Study 4 also support the assumption that android robots are at a category boundary between robots or machines on the one hand and humans on the other hand. Android robots and artificial humans were most often falsely categorized, decisions between these two stimulus categories were not as clear as other decisions and participants reported to be least confident of these decisions compared to other decisions. These are all indicators for uncertainty (in this case perceptual) at category boundaries (Cheetham et al., 2011; Cheetham et al., 2013; Yamada et al., 2013).

In Study 4, *evolutionary-biological explanations* were the focus. It was examined whether uncanny valley related reactions on the behavioral level were induced by disgust. Hence the stimulus material included not only robots but also healthy humans and disabled humans which supposedly also provide heuristic disease cues and thus might elicit responses from the behavioral immune system (Park et al., 2003; Park et al., 2007; Schaller & Park, 2011). However, none of the hypothesized effects emerged. Although it was found that confidence ratings correlated with activation in the insula at the time of choice, this result remains inconclusive, because the insula is known to be involved in many different processes, not only in the experience of disgust. Since the functional localizer for disgust failed, no conclusions can be made whether the activated voxels are related to disgust or the experience of other emotions. Few answers in the interviews in Study 1 indicated that the appearance of CB2 elicited disgust, because it reminded participants of a ghost or an alien. Altogether, there is no strong support for the assumption that uncanny valley reactions are caused by an oversensitivity bias in the behavioral immune system as has been suggested previously (Burleigh et al., 2013; Ho et al., 2008; MacDorman, 2005b; MacDorman & Ishiguro, 2006; Park et al., 2003).

Regarding *perception-oriented explanations*, the results of Study 4 support the assumption that mismatches in expectations about perceptions and actual perceptions in whatever form cause additional processing on how to interpret, categorize, or react to the stimuli which causes uncertainty and is thus negatively interpreted (e.g. MacDorman et al., 2009). Robotic faces seem to trigger the common template for faces due to their geometrical characteristics (cf. Hadjikhani et al., 2009; Kanwisher et al., 1997; Pinker, 1997), but increased brain activity is needed in the fusiform face area to decide on whether a real face is perceived or not. These findings are in line with previous work demonstrating that additional processing is needed to code a robot face as a face (Chaminade et al., 2010; Cheetham et al., 2011; Dubal et al., 2011; Gobbini et al., 2011). Moreover, the results of Study 4 showed that increased human-likeness is associated with increased activity in ToM relevant brain areas as was found in previous studies (cf. Krach et al., 2008). It seems that participants engaged in mentalizing or theory of mind processes to infer what reward the robots and people presented might have picked, in order to come to the decision regarding which of the two stimuli might be the more favorable choice for the participants. The observed effects follow a similar pattern as the activation patterns regarding face perception. This is a quite intuitive finding, because processes of social cognition should ideally be elicited by humans and not by any everyday object (Adolphs, 1999; Amodio & Frith, 2006; Saxe, 2006). Hence, more human-like objects also evoke more processes of social cognition. This finding also supports Nass and Reeves' (Reeves & Nass, 1996) media equation theory which is based on the assumption that "absent a significant warning that we've been fooled, our old brains hold sway and we accept media as real people and places" (Reeves & Nass, 1996, p. 12).

Altogether, this work found strong support for *perception-oriented explanations* for the uncanny valley effect. First, effects seemed to be driven by additional processing during face perception. Further, as mentioned above, there were indicators for the assumption that categorical perception took place. However, more systematic research is needed with regard to categorical processing, because the experimental paradigm was not explicitly designed to test for this phenomenon.

6. Future research

The present work addressed a number of open research questions identified at the end of the literature review. However, this work is certainly not ultimately conclusive. There are still open questions, for instance, whether the uncanny valley reaction is a short-term phenomenon which can be overcome by habituation (Brenton et al., 2005). Moreover, the studies presented in this work were subject to certain limitations leaving room for further investigation.

For instance, none of the studies included industrial or zoomorphic robots. Thus, no conclusions can be drawn on participants' perceptions and evaluations of (even) more mechanical looking robots or zoomorphic robots. Although parts of the stimulus material were consistent throughout the studies, it was varied and refined according to the specific research questions of the particular study. Moreover, a variety of different measures have been used. On the one hand, this procedure allowed the drawing of interesting conclusions also with regard to the importance of the experimental paradigms in which the uncanny valley is examined, but on the other hand it sometimes hindered the generalization of findings. However, the current work showed how great the influence of the choice of measurements is, and demonstrated the importance of standardized stimulus material. Thus, future work should investigate the uncanny valley more systematically using more standardized material. Moreover, a variety of measures should be included. This is not only important with regard to questionnaire items (e.g. different effects for likable and threatening, or human-like and mechanical), but also with regard to additional measures (behavior, psychophysiology) which should be included.

In Study 1, a comparison of adults' and children's perceptions of the individual robots was not possible, because especially the younger children had difficulties in expressing their feelings when asked for them. Thus, there were no reliable data on how the children perceived the robots and whether they experienced emotional reactions. It seems that in further studies involving children, other measures have to be used in order to gather meaningful data. However, the effects found were very interesting and further investigations on age effects are certainly interesting and needed. Moreover, the study included German and Malayan participants. The reported cultural differences are indeed interesting, but only preliminary findings, which have to be investigated more systematically. Thus future work, Analyses should also include more different cultures to explore the role of cultural background with regard to the uncanny valley hypothesis.

One major limitation of Study 2 was that the sample was self-selective. This caused an uneven distribution over the conditions, because, for instance, fewer people happened to agree to participate on the days when we installed the *still* set-up. Only those participants who agreed to engage in interviews were included in the video evaluation and this might have skewed the results. For future analyses it would be interesting to analyze the interactions of all persons interacting with a robot placed in a public scene not only of those who engaged in interviews after an interaction (cf. Kanda, Ishiguro, Ono, Imai, & Nakatsu, 2002; Hayashi et al., 2007). Moreover, the data could be qualitatively analyzed using interaction analysis and conversation analysis techniques.

With regard to Study 3 a replication of the study would be needed in order to achieve generalization of the results of the PCA. Although the participants ratings for a subset of twelve robots in Study 3b overall corresponded to the ratings in Study 3a, which is a good sign that the results of Study 3a are reliable. Moreover, there seemed to be effects of demand characteristics or socially desirable answering behavior with regard to the likability ratings, because a strong central tendency was observable. Most importantly, the stimulus material did not reflect the whole human-likeness scale depicted by Mori, because the sample did not include pictures of healthy humans or, for instance, industrial robots. This was, however, not the case in Study 4 in which human stimuli were also included. The results of the curve discussion were different between the studies and this might be related to the choice of stimulus material. For future work it would be interesting to also include even more mechanical robots (e.g. industrial robots arms) and zoomorphic robots. Moreover, it would be very interesting to apply the same approach to standardized videos of the different robots which perform gradually varied movements in order to investigate the relationship of appearance and movement.

The main limitation of Study 4 is that the functional localizers for the fusiform face area and disgust related areas failed due to technical problems. Therefore, conclusions with regard to whether the effect found for the insula was disgust related or not were not possible. In addition, it would be interesting to use a variety of localizers for different emotional states (e.g. disgust, fear) in order to shed light onto the question of whether uncanny valley related reactions are based on the experience of emotional states. Moreover, it would have been more favorable to base analyses and the conclusions on a combination of functional localization and literature-based localization with regard to the face-processing. Finally, the reported functional imaging results in Study 4 are based on whole-brain analyses. Region of interest analyses will be performed in the specified brain regions of interest in future work.

The results of Study 1, 2 and 4 suggested processes of categorical perception. In future work, this should be investigated in more detail, for instance, with more gradually varied material on the continuum robot-human which could bring more insight into this question.

VIII. CONCLUSION

In this research project, it was examined how different kinds of robots are perceived with regard to dimensions relevant for the uncanny valley hypothesis. Hence, the studies focused on how static and dynamic characteristics of robots determine evaluations of and behavior towards robots. Especially, the importance of the appearance of robots was considered and design characteristics have been identified which determine evaluations of robots as, for instance, human-like, threatening, familiar and likable. Further, neural correlates for the perception and evaluation of robots have been identified. Since the current results are based on standardized stimulus material the results make a substantial contribution to the state of the art. Furthermore, sophisticated analyses were used to critically discuss how well the proposed uncanny valley curve fits to actually obtained data. The results revealed that unlike proposed by Mori, there is only weak evidence for a non-linear relationship. Moreover, the occurences of non-linear relationships were greatly influenced by the choice of measurements. This leads to the conclusion that although negative responses in HRI are observable, there is no striking evidence for the proposed non-linear relationship of the uncanny valley. A first attempt has been made to explore the influence of robotic movement and to examine whether movement aggravates uncanny valley related responses. The results demonstrated the importance of the robots' movements and the social context they were placed in with regard to the evaluation of these robots. Further, a robots movement can serve as cue for the participants to categorize the robot as such and thus have a positive effect. Altogether, the movement of very human-like robots showed rather positive than negative effects and certainly did not result in aggrevated negative responses. The major contribution of this work is the systematic investigation of explanations for the occurrence of the uncanny valley. The results do not support the assumption that the observed effects stem from emotional processes. In contrast, perception-oriented explanations (additional processing during face perception, categorical perception) and cognitive-oriented explanations were supported.

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X. Appendix

Appendix A: Study 1

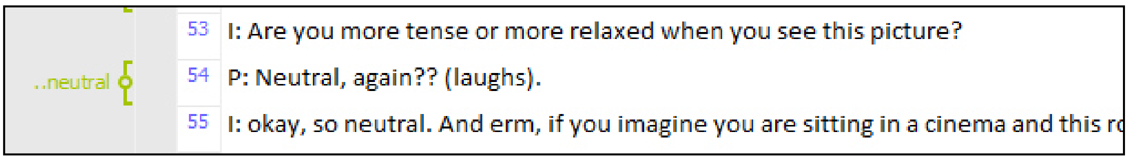
Coding Manual

- Identify the particular question.
- Code the answer.
    - Code answer without including the interviewer's question.
    - In case interviewee asks a question him/herself in order to understand the one posed by the interviewer, this should not be included in the coded answer. Only answers related to the actual question should be coded.
    - Unit of coding is one statement answering a question. This can either include a single line (cf. example A) or include multiple lines (cf. example B). In the latter case, the interviewer's inquiries are included in the coding.
- Besides a limited number of exceptions (see below), each code can only be allocated once in a document. If a particular question is discussed twice in the course of the interview, only the first occurrence should be coded.
- In case participants wander from the subject after a question is posed this passages should not be coded (cf. red parenthesis in example C).

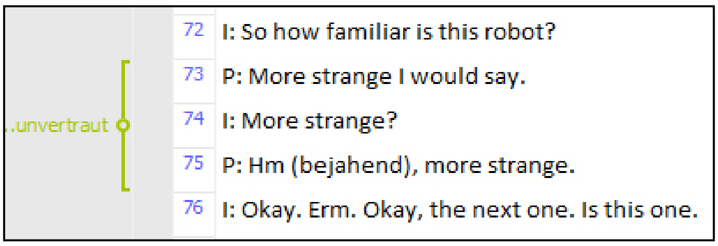
Exceptions that can occur:

- At the interviewer forgets to ask a question from the interview guideline. If this is the case, this question cannot be coded unless the interviewee addressed and answered the question himself (e.g. after a while participants know the order of the questions and sometimes give a statement answering several questions).
- If a statement could be coded with several codes, the coder has decide for the most favorable code and has to mark the answer with a *MEMO* so that coders can discuss about the answer later.

Example A



Example B



Beispiel C

43 I: Okay. So let me start with the picture. (CHILD) Okay, when you look at this picture, how do you fell when you look at this picture? What´s your emotion when you´re looking at the picture.

44 P: It look like a kid to me it looks, looks more childlike this robot and maybe looks a bit sad. Ja. Because seems, gives the impression that this robot is lacking something, to me.

45 I: Ja -- so that it is in need for something?

46 P: Ja it has the need for something. Or it is not complete in a sense.

47 I: Ja, okay. And how does it make you feel? Do you have a positive or negative feeling when you look at that? So does it cause any feelings?

48 P: Not really I think I,-- neutral?

49 I: Neutral? (both laugh).

..neutral

50 P: Ja?

51 I: Is also okay (both laugh).

52 P: Ja, neutral I´d say.

53 I: Are you more tense or more relaxed when you see this picture?

Appendix B: Study 3

Example page of the online questionnaire

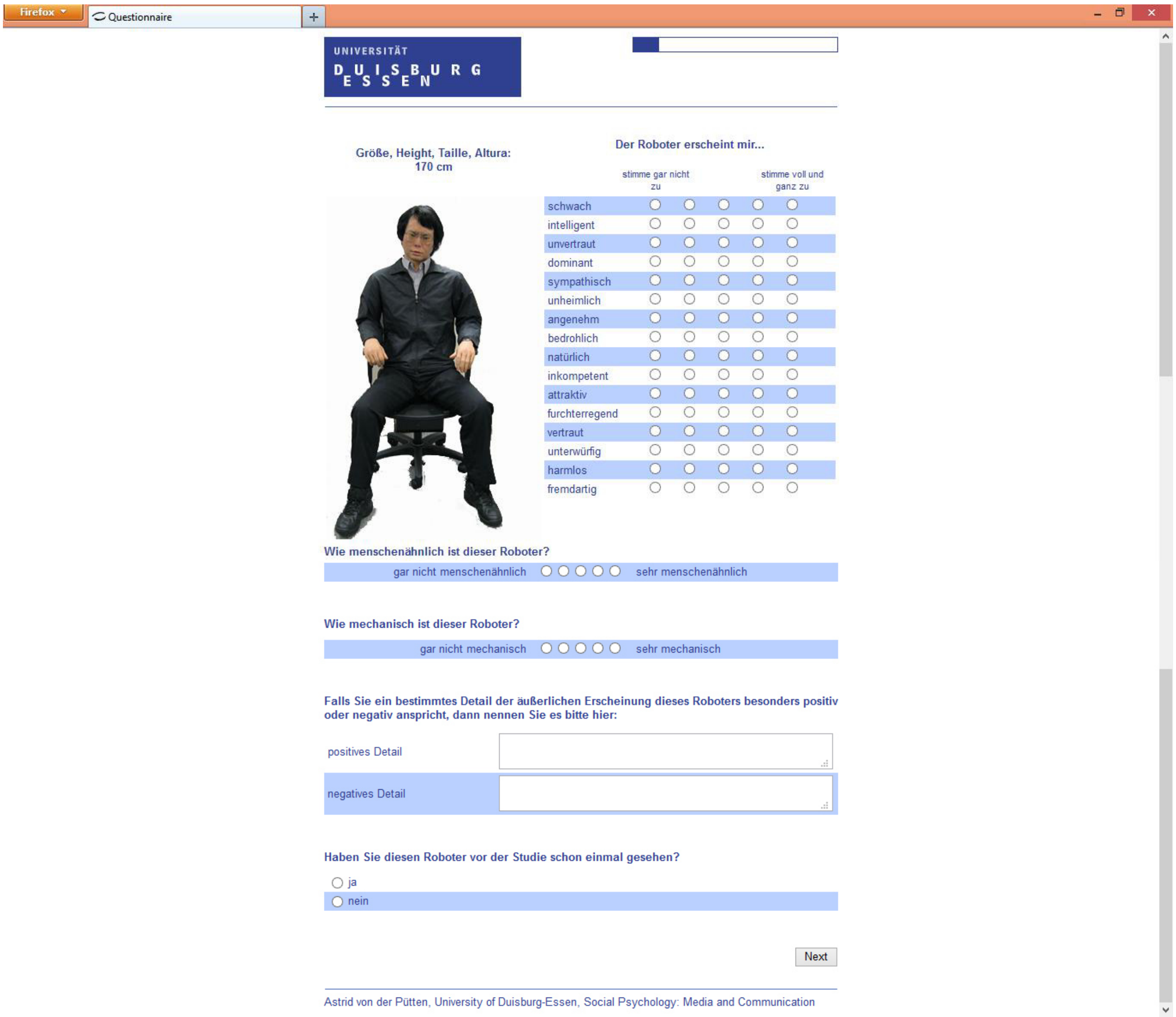


Table 60: Mean differences and standard errors for multiple comparisons of clusters with regard to likable ratings using the Tukey post-hoc test

(I)Cluster	(J)Cluster	Mean difference (I-J)	Standard error	p	95% CI Lower	95% CI Upper
1	2	.5972*	.09944	.000	.2971	.8974
	3	.3761	.14749	.138	-.0691	.8212
	4	-.5247*	.14749	.013	-.9698	-.0795
	5	.6098*	.08480	.000	.3538	.8657
	6	.5111*	.08669	.000	.2495	.7728
2	1	-.5972*	.09944	.000	-.8974	-.2971
	3	-.2212	.15404	.706	-.6861	.2438
	4	-1.1219*	.15404	.000	-1.5869	-.6570
	5	.0125	.09575	1.000	-.2765	.3015
	6	-.0861	.09743	.948	-.3802	.2079
3	1	-.3761	.14749	.138	-.8212	.0691
	2	.2212	.15404	.706	-.2438	.6861
	4	-.9008*	.18866	.000	-1.4702	-.3313
	5	.2337	.14503	.597	-.2040	.6714
	6	.1351	.14614	.937	-.3060	.5761
4	1	.5247*	.14749	.013	.0795	.9698
	2	1.1219*	.15404	.000	.6570	1.5869
	3	.9008*	.18866	.000	.3313	1.4702
	5	1.1345*	.14503	.000	.6967	1.5722
	6	1.0358*	.14614	.000	.5947	1.4769
5	1	-.6098*	.08480	.000	-.8657	-.3538
	2	-.0125	.09575	1.000	-.3015	.2765
	3	-.2337	.14503	.597	-.6714	.2040
	4	-1.1345*	.14503	.000	-1.5722	-.6967
	6	-.0986	.08243	.835	-.3475	.1502
6	1	-.5111*	.08669	.000	-.7728	-.2495
	2	.0861	.09743	.948	-.2079	.3802
	3	-.1351	.14614	.937	-.5761	.3060
	4	-1.0358*	.14614	.000	-1.4769	-.5947
	5	.0986	.08243	.835	-.1502	.3475

Table 61: Mean differences and standard errors for multiple comparisons of clusters with regard to threatening ratings using the Tukey post-hoc test

					95% CI	
(I)Cluster	(J)Cluster	Mean difference (I-J)	Standard error	p	Lower	upper
1	2	-.1743	.14314	.825	-.6063	.2577
	3	-1.3169*	.21230	.000	-1.9577	-.6762
	4	-.8297*	.21230	.005	-1.4705	-.1890
	5	-1.0814*	.12207	.000	-1.4499	-.7130
	6	-.4730*	.12478	.007	-.8496	-.0964
2	1	.1743	.14314	.825	-.2577	.6063
	3	-1.1427*	.22174	.000	-1.8119	-.4734
	4	-.6555	.22174	.058	-1.3247	.0138
	5	-.9071*	.13783	.000	-1.3231	-.4911
	6	-.2987	.14024	.297	-.7220	.1246
3	1	1.3169*	.21230	.000	.6762	1.9577
	2	1.1427*	.22174	.000	.4734	1.8119
	4	.4872	.27158	.483	-.3325	1.3069
	5	.2355	.20877	.866	-.3946	.8656
	6	.8440*	.21036	.004	.2090	1.4789
4	1	.8297*	.21230	.005	.1890	1.4705
	2	.6555	.22174	.058	-.0138	1.3247
	3	-.4872	.27158	.483	-1.3069	.3325
	5	-.2517	.20877	.831	-.8818	.3784
	6	.3568	.21036	.544	-.2782	.9917
5	1	1.0814*	.12207	.000	.7130	1.4499
	2	.9071*	.13783	.000	.4911	1.3231
	3	-.2355	.20877	.866	-.8656	.3946
	4	.2517	.20877	.831	-.3784	.8818
	6	.6084*	.11866	.000	.2503	.9666
6	1	.4730*	.12478	.007	.0964	.8496
	2	.2987	.14024	.297	-.1246	.7220
	3	-.8440*	.21036	.004	-1.4789	-.2090
	4	-.3568	.21036	.544	-.9917	.2782
	5	-.6084*	.11866	.000	-.9666	-.2503

Table 62: Mean differences and standard errors for multiple comparisons of clusters with regard to submissive ratings using the Tukey post-hoc test

					95% CI	
(I)Cluster	(J)Cluster	Mean difference (I-J)	Standard error	p	lower	upper
1	2	-.2736	.14967	.462	-.7254	.1781
	3	.3058	.22199	.740	-.3642	.9758
	4	.7516*	.22199	.021	.0815	1.4216
	5	.8532*	.12764	.000	.4680	1.2385
	6	.4625*	.13048	.014	.0687	.8563
2	1	.2736	.14967	.462	-.1781	.7254
	3	.5795	.23187	.153	-.1204	1.2793
	4	1.0252*	.23187	.001	.3254	1.7250
	5	1.1269*	.14412	.000	.6919	1.5619
	6	.7361*	.14664	.000	.2935	1.1787
3	1	-.3058	.22199	.740	-.9758	.3642
	2	-.5795	.23187	.153	-1.2793	.1204
	4	.4458	.28398	.623	-.4114	1.3029
	5	.5474	.21829	.150	-.1115	1.2063
	6	.1567	.21997	.979	-.5072	.8206
4	1	-.7516*	.22199	.021	-1.4216	-.0815
	2	-1.0252*	.23187	.001	-1.7250	-.3254
	3	-.4458	.28398	.623	-1.3029	.4114
	5	.1017	.21829	.997	-.5572	.7605
	6	-.2891	.21997	.775	-.9530	.3748
5	1	-.8532*	.12764	.000	-1.2385	-.4680
	2	-1.1269*	.14412	.000	-1.5619	-.6919
	3	-.5474	.21829	.150	-1.2063	.1115
	4	-.1017	.21829	.997	-.7605	.5572
	6	-.3907*	.12408	.037	-.7652	-.0162
6	1	-.4625*	.13048	.014	-.8563	-.0687
	2	-.7361*	.14664	.000	-1.1787	-.2935
	3	-.1567	.21997	.979	-.8206	.5072
	4	.2891	.21997	.775	-.3748	.9530
	5	.3907*	.12408	.037	.0162	.7652

Table 63: Mean differences and standard errors for multiple comparisons of clusters with regard to unfamiliar ratings using the Tukey post-hoc test

					95% CI	
(I)Cluster	(J)Cluster	Mean difference (I-J)	Standard error	p	lower	upper
1	2	-.2361	.10578	.250	-.5554	.0832
	3	.5355*	.15689	.019	.0620	1.0091
	4	.7184*	.15689	.001	.2449	1.1919
	5	-.1745	.09021	.400	-.4468	.0978
	6	-.5563*	.09221	.000	-.8346	-.2779
2	1	.2361	.10578	.250	-.0832	.5554
	3	.7716*	.16387	.001	.2771	1.2662
	4	.9545*	.16387	.000	.4599	1.4491
	5	.0616	.10186	.990	-.2458	.3690
	6	-.3202*	.10364	.042	-.6330	-.0074
3	1	-.5355*	.15689	.019	-1.0091	-.0620
	2	-.7716*	.16387	.001	-1.2662	-.2771
	4	.1828	.20070	.941	-.4229	.7886
	5	-.7101*	.15428	.001	-1.1757	-.2444
	6	-1.0918*	.15546	.000	-1.5610	-.6226
4	1	-.7184*	.15689	.001	-1.1919	-.2449
	2	-.9545*	.16387	.000	-1.4491	-.4599
	3	-.1828	.20070	.941	-.7886	.4229
	5	-.8929*	.15428	.000	-1.3586	-.4273
	6	-1.2747*	.15546	.000	-1.7439	-.8054
5	1	.1745	.09021	.400	-.0978	.4468
	2	-.0616	.10186	.990	-.3690	.2458
	3	.7101*	.15428	.001	.2444	1.1757
	4	.8929*	.15428	.000	.4273	1.3586
	6	-.3818*	.08769	.002	-.6464	-.1171
6	1	.5563*	.09221	.000	.2779	.8346
	2	.3202*	.10364	.042	.0074	.6330
	3	1.0918*	.15546	.000	.6226	1.5610
	4	1.2747*	.15546	.000	.8054	1.7439
	5	.3818*	.08769	.002	.1171	.6464

Table 64: Mean differences and standard errors for multiple comparisons of clusters with regard to human-like ratings using the Tukey post-hoc test

					95% CI	
(I)Cluster	(J)Cluster	Mean difference (I-J)	Standard error	p	lower	upper
1	2	.1561	.27373	.992	-.6701	.9823
	3	-2.3206*	.40600	.000	-3.5460	-1.0951
	4	-2.4106*	.40600	.000	-3.6360	-1.1851
	5	-.5210	.23343	.250	-1.2256	.1836
	6	.2904	.23863	.825	-.4298	1.0107
2	1	-.1561	.27373	.992	-.9823	.6701
	3	-2.4767*	.42405	.000	-3.7566	-1.1968
	4	-2.5667*	.42405	.000	-3.8466	-1.2868
	5	-.6771	.26358	.133	-1.4727	.1184
	6	.1343	.26820	.996	-.6751	.9438
3	1	2.3206*	.40600	.000	1.0951	3.5460
	2	2.4767*	.42405	.000	1.1968	3.7566
	4	-.0900	.51936	1.000	-1.6575	1.4775
	5	1.7995*	.39923	.001	.5946	3.0045
	6	2.6110*	.40229	.000	1.3968	3.8252
4	1	2.4106*	.40600	.000	1.1851	3.6360
	2	2.5667*	.42405	.000	1.2868	3.8466
	3	.0900	.51936	1.000	-1.4775	1.6575
	5	1.8895*	.39923	.001	.6846	3.0945
	6	2.7010*	.40229	.000	1.4868	3.9152
5	1	.5210	.23343	.250	-.1836	1.2256
	2	.6771	.26358	.133	-.1184	1.4727
	3	-1.7995*	.39923	.001	-3.0045	-.5946
	4	-1.8895*	.39923	.001	-3.0945	-.6846
	6	.8115*	.22692	.013	.1265	1.4964
6	1	-.2904	.23863	.825	-1.0107	.4298
	2	-.1343	.26820	.996	-.9438	.6751
	3	-2.6110*	.40229	.000	-3.8252	-1.3968
	4	-2.7010*	.40229	.000	-3.9152	-1.4868
	5	-.8115*	.22692	.013	-1.4964	-.1265

Table 65: Mean differences and standard errors for multiple comparisons of clusters with regard to mechanical ratings using the Tukey post-hoc test

					95% CI	
(I)Cluster	(J)Cluster	Mean difference (I-J)	Standard error	p	lower	upper
1	2	-.3161	.20778	.653	-.9432	.3110
	3	1.0839*	.30819	.015	.1537	2.0141
	4	.9239	.30819	.052	-.0063	1.8541
	5	-.9538*	.17719	.000	-1.4887	-.4190
	6	-.6521*	.18114	.012	-1.1988	-.1054
2	1	.3161	.20778	.653	-.3110	.9432
	3	1.4000*	.32189	.002	.4285	2.3715
	4	1.2400*	.32189	.006	.2685	2.2115
	5	-.6377*	.20008	.033	-1.2416	-.0338
	6	-.3360	.20358	.572	-.9505	.2785
3	1	-1.0839*	.30819	.015	-2.0141	-.1537
	2	-1.4000*	.32189	.002	-2.3715	-.4285
	4	-.1600	.39423	.998	-1.3499	1.0299
	5	-2.0377*	.30305	.000	-2.9524	-1.1231
	6	-1.7360*	.30537	.000	-2.6577	-.8143
4	1	-.9239	.30819	.052	-1.8541	.0063
	2	-1.2400*	.32189	.006	-2.2115	-.2685
	3	.1600	.39423	.998	-1.0299	1.3499
	5	-1.8777*	.30305	.000	-2.7924	-.9631
	6	-1.5760*	.30537	.000	-2.4977	-.6543
5	1	.9538*	.17719	.000	.4190	1.4887
	2	.6377*	.20008	.033	.0338	1.2416
	3	2.0377*	.30305	.000	1.1231	2.9524
	4	1.8777*	.30305	.000	.9631	2.7924
	6	.3017	.17225	.509	-.2182	.8216
6	1	.6521*	.18114	.012	.1054	1.1988
	2	.3360	.20358	.572	-.2785	.9505
	3	1.7360*	.30537	.000	.8143	2.6577
	4	1.5760*	.30537	.000	.6543	2.4977
	5	-.3017	.17225	.509	-.8216	.2182

Appendix C: Study 4

Table 66: Mean differences and standard errors for multiple comparisons of clusters with regard to confidence ratings using the Bonferroni post-hoc test

(I)Contrast	(J)Contrast	Mean difference (I-J)	Standard error	p	95% CI lower	95% CI upper
1	2	.538*	.068	.000	.291	.785
	3	.898*	.092	.000	.564	1.232
	4	-.005	.087	1.000	-.318	.308
	5	.512*	.104	.002	.135	.888
	6	.601*	.095	.000	.259	.944
	7	-.030	.077	1.000	-.308	.249
	8	-.016	.076	1.000	-.292	.260
	9	.826*	.089	.000	.504	1.148
2	1	-.538*	.068	.000	-.785	-.291
	3	.360*	.082	.007	.065	.655
	4	-.543*	.101	.001	-.907	-.178
	5	-.026	.132	1.000	-.505	.452
	6	.063	.085	1.000	-.244	.371
	7	-.568*	.095	.000	-.910	-.225
	8	-.554*	.090	.000	-.878	-.231
	9	.288	.084	.083	-.017	.593
3	1	-.898*	.092	.000	-1.232	-.564
	2	-.360*	.082	.007	-.655	-.065
	4	-.903*	.110	.000	-1.300	-.506
	5	-.386	.111	.067	-.786	.013
	6	-.297	.104	.316	-.672	.079
	7	-.928*	.099	.000	-1.286	-.569
	8	-.914*	.103	.000	-1.285	-.543
	9	-.072	.085	1.000	-.381	.236
4	1	.005	.087	1.000	-.308	.318
	2	.543*	.101	.001	.178	.907
	3	.903*	.110	.000	.506	1.300
	5	.516*	.115	.006	.100	.933
	6	.606*	.117	.001	.183	1.030
	7	-.025	.074	1.000	-.290	.241
	8	-.011	.072	1.000	-.271	.248
	9	.831*	.090	.000	.505	1.157
5	1	-.512*	.104	.002	-.888	-.135
	2	.026	.132	1.000	-.452	.505
	3	.386	.111	.067	-.013	.786
	4	-.516*	.115	.006	-.933	-.100
	6	.090	.108	1.000	-.302	.482

	7	-.541*	.113	.003	-.950	-.133
	8	-.528*	.123	.009	-.972	-.084
	9	.314	.108	.269	-.074	.703
6	1	-.601*	.095	.000	-.944	-.259
	2	-.063	.085	1.000	-.371	.244
	3	.297	.104	.316	-.079	.672
	4	-.606*	.117	.001	-1.030	-.183
	5	-.090	.108	1.000	-.482	.302
	7	-.631*	.109	.000	-1.026	-.236
	8	-.618*	.114	.001	-1.030	-.206
	9	.224	.072	.165	-.035	.484
7	1	.030	.077	1.000	-.249	.308
	2	.568*	.095	.000	.225	.910
	3	.928*	.099	.000	.569	1.286
	4	.025	.074	1.000	-.241	.290
	5	.541*	.113	.003	.133	.950
	6	.631*	.109	.000	.236	1.026
	8	.013	.069	1.000	-.237	.263
	9	.855*	.089	.000	.533	1.178
8	1	.016	.076	1.000	-.260	.292
	2	.554*	.090	.000	.231	.878
	3	.914*	.103	.000	.543	1.285
	4	.011	.072	1.000	-.248	.271
	5	.528*	.123	.009	.084	.972
	6	.618*	.114	.001	.206	1.030
	7	-.013	.069	1.000	-.263	.237
	9	.842*	.079	.000	.556	1.128
9	1	-.826*	.089	.000	-1.148	-.504
	2	-.288	.084	.083	-.593	.017
	3	.072	.085	1.000	-.236	.381
	4	-.831*	.090	.000	-1.157	-.505
	5	-.314	.108	.269	-.703	.074
	6	-.224	.072	.165	-.484	.035
	7	-.855*	.089	.000	-1.178	-.533
	8	-.842*	.079	.000	-1.128	-.556